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REDUCING NITROGEN OUTPUT FROM INTENSIVE BEEF AND DAIRY CATTLE OPERATIONS

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REDUCING NITROGEN OUTPUT FROM INTENSIVE BEEF AND DAIRY CATTLE OPERATIONS

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A. SUMMARY:

The overall objective of this research project was to investigate the effects of source of dietary carbohydrate, cereal grain processing, and dietary protein on urea transfer to the rumen, rumen microbial protein production, animal performance, and whole animal nitrogen (N) balance in beef and dairy cattle reared under intensive management conditions. In Experiment 1, 8 Holstein cows were used in a replicated 4 x 4 Latin square design to determine the effects of 4 sources of carbohydrate (barley, corn, wheat, or oats grain) on milking performance, N balance, and microbial N flow to the duodenum. Intake of DM tended to be lower in cows fed the wheat-based diet compared to those fed the barley-based diet; consequently, milk yield tended to be lower in cows fed the wheat-based diet compared to those fed the barley-based diet. Nitrogen that was used for productive purposes (i.e., N secreted in milk + N apparently retained by the cow) tended to be lower in cows fed the wheat- based diet compared to cows fed the barley-, corn- or oats-based diets. Urinary purine derivative (PD) excretion was similar in cows fed the barley-, corn-, and wheat-based diets; however, PD excretion was higher in cows fed the barley-based diet compared to those fed the oats-based diet. Consequently, estimated microbial N flow to the duodenum was 49 g/d higher in cows fed the barley-based diet compared to those fed the oats-based diet. Improved production performance with corn and barley diets appeared to be due to greater nutrient absorption than in cows fed oats and wheat diets, rather than improved nutrient utilization efficiency. In Experiment 2, the objective was to determine the effects of methods of barley grain processing and source of supplemental fat on urea-N transfer to the gastrointestinal tract (GIT) and the utilization of this recycled urea-N in lactating dairy cows. Four rumen-cannulated Holstein cows were used in a 4 x 4 Latin square design with 28-d periods and a 2 x 2 factorial arrangement of dietary treatments. Experimental diets contained either dry-rolled barley or pelleted barley in combination with either whole canola or whole flaxseed as supplemental fat sources. Dry matter

intake and N intake were higher in cows fed dry-rolled barley compared to those fed pelleted barley. Nitrogen retention was not affected by diet, but fecal N excretion was higher in cows fed dry-rolled barley than in those fed pelleted barley. Milk yield was unaffected by diet. Urea-N production was higher (442.2 vs 334.3 g N/d), and urea-N entering the GIT tended to be higher (272.9 vs 202.0 g N/d), in cows fed dry-rolled barley compared to those fed pelleted barley. The amount of urea-N entry into the GIT that was returned to the ornithine cycle was higher (204.1 vs 159.5 g N/d) in cows fed dry-rolled barley than in pelleted barley fed cows. The amount of urea-N recycled to the GIT and used for anabolic purposes, and the amounts lost in the urine or feces were not affected by dietary treatment. Microbial non-ammonia N supply, estimated using total urinary excretion of purine derivatives, was not affected by diet. These results show that even though barley grain processing altered urea-N entry into the GIT, the utilization of this recycled urea-N for microbial production was unaffected as the additional urea-N which entered the GIT was returned to ureagenesis. In Experiment 3, the objective was to determine the effects of dietary levels of crude protein (**CP**; 10 vs. 13%) and rumen-degradable protein (**RDP**; 29 vs. 35.5%) on urea recycling to the GIT, microbial protein **(MP)** synthesis and N balance of growing heifers. Four rumen- and duodenally-cannulated beef heifers were used in a 4 × 4 Latin square design with a 2 × 2 factorial arrangement of dietary treatments. Endogenous urea-N production increased with dietary CP level, as did urinary urea-N loss; however, urea-N transfer to the GIT was similar across diets. Microbial N supply was unaffected by diet. Therefore, in the short term, 10% CP diets showed greater efficiency of N utilization, less N excreted into the environment with no associated change in microbial protein production.

B. INTRODUCTION:

On a worldwide basis, including Saskatchewan, public concern about environmental damage that is instigated by intensive livestock (cattle, pigs, poultry) feeding operations has increased in recent years. For beef and dairy operations, feeding cattle in confinement as is common practice in Saskatchewan results in the concentration of nutrients such as nitrogen (N) and phosphorus (P), which pose a threat to the environment. Increased concern for environmental protection has resulted in most governments around the world where intensive livestock operations exist introducing nutrient management legislation to monitor nutrient output into the environment (Van Horn et al., 1996; CAST, 2002). In Saskatchewan, the Ministry of Agriculture, Food, and Rural Revitalization is seriously concerned about the negative environmental impact of confined livestock operations, and one of its major priorities is to ".....support research and development to develop improved and environmentally sustainable practices...." (Source: www.agr.gov.sk.ca/research).

In intensive beef and dairy operations, N is considered to be the most critical manure nutrient from an environmental standpoint (Van Horn et al., 1996; Galyean, 1996; Klopfenstein and Erickson, 2002); however, attempts to enhance the efficiency of N use for meat and milk production have been hampered by the complex, dynamic nature of protein nutrition in ruminants (NRC, 1996; NRC, 2001). In both lactating dairy cows and growing/fattening beef cattle, N in the form of crude protein (CP) is an important feed nutrient for the production of milk and meat. A serious disadvantage is that the conversion of feed N into animal protein is relatively inefficient in cattle. For example, in dairy cows, only 25 to 30% of N intake is converted to milk protein (Tamminga, 1992; Haig et al., 2002). So, a typical lactating dairy cow fed with a dietary CP concentration of 160 g/kg of feed dry matter (DM) and consuming 22 kg DM/day, will excrete 750 to 805 kg of CP per lactation (305 d). With a dairy cow population of 42,000 in Saskatchewan,

total annual CP output into the environment is approximately 31.6 to 33.8 million kg! In feedlot cattle, the efficiency of dietary N use is even poorer, with only 15% of N intake being retained in the body (Galyean, 1996). So, a typical feedlot steer fed with a dietary CP concentration of 130 g/kg of feed DM and consuming 10 kg DM/day, will excrete approximately 138 kg of CP into the environment during 125 days in a feedlot. With approximately 200,000 head of cattle going through Saskatchewan feedlots annually, total output of CP into the environment is 27.6 million kg! Intensive beef and dairy operations, therefore, are responsible for discharging staggering amounts of N that are harmful to the environment, and there is an urgent need for research to improve the efficiency of N use in cattle so as to reduce environmental degradation in Saskatchewan. The partitioning of N output between faeces and urine is very important. Urinary N usually accounts for 60 to 80% of total N excretion, and most of this N is in the form of urea (Van Horn et al., 1996). As much as 75% of urea-N can be rapidly lost into the environment via volatilization (CAST, 2002).

Urea, which is the primary end-product of N catabolism in cattle, is largely excreted in urine. However, cattle have evolved a mechanism that allows the constant recycling of urea to the gastrointestinal tract (GIT) where it can be used for microbial protein production which, in turn, can supply protein to the host animal. This evolutionary adaptation provides cattle with a mechanism to conserve N (Huntington, 1986). Huntington (1989) estimated that 40 to 60% of liver urea output is recycled to the digestive tract. An additional advantage of increasing urea recycling is reduced environmental degradation. Therefore, we can enhance the efficiency of N utilization by increasing urea recycling and its conversion to microbial protein. Limited understanding of the feeding conditions that control urea recycling to the GIT has limited our ability to manipulate urea recycling so as to improve production efficiency. Limited research has indicated that the amount of urea that is recycled to the digestive tract and subsequently used for anabolic purposes can be

influenced by a variety of dietary factors, including the level of feed intake (Sarraseca et al., 1998), level of concentrate (Huntington et al., 1996), and level of dietary N (Bunting et al., 1987; Archibeque et al., 2001). In beef cattle, increasing ruminal supply of readily fermentable carbohydrates increased urea transfer to the rumen (Huntington, 1989) and this was associated with decreased total N excretion (Reynolds and Huntington, 1988). Recently, Theurer et al. (1999; 2002) demonstrated that shifting the site of starch digestion from the small intestine to the rumen by steam-flaking sorghum grain resulted in increased urea recycling to the rumen, greater supply of microbial protein to the duodenum, and higher whole-body N retention in beef steers. Under Saskatchewan beef and dairy feeding conditions, research is needed to examine the effects of source of dietary non-structural carbohydrate (NSC) or different cereal grain processing methods on urea recycling to the rumen and, subsequently, effects on whole animal N balance and N excretion into the environment. In Saskatchewan, barley, wheat, and oats are commonly used as the cereal base in beef and dairy cattle diets. The use of corn is also increasing because frequent droughts are decreasing the availability and increasing the relative cost of barley and wheat. These cereal grains differ in their content of NSC and their rates and extents of ruminal degradation of NSC, and this would influence the site of starch digestion and, subsequently, efficiency of N incorporation into microbial protein. Furthermore, cereal grain processing methods such as grinding, dry-rolling or steam-flaking, which are commonly used in western Canadian feed mills, will also alter the rates and extents of ruminal degradation of NSC, but their effects on urea recycling have not been studied. An intriguing area that has not received any attention is the impact of judicious blends of the various cereal grains (e.g., corn and barley), either whole or processed, which are designed to complement each other in terms of ruminal degradation of NSC so as to provide an optimum environment for urea recycling and microbial protein production.

The overall objective of this research project was to investigate the effects of source of

dietary carbohydrate, cereal grain processing, and dietary protein on urea transfer to the rumen, ruminal microbial protein production, animal performance, and whole animal N balance in beef and dairy cattle reared under intensive management conditions.

C. MATERIALS AND METHODS:

1. Experiment 1:

1.1. ***Objectives:*** The objective of the study was to evaluate the effect of dietary inclusion of barley, corn, wheat, or oats as the principal source of starch on microbial N flow to the duodenum, performance and N retention in dairy cows.

1.2. Animals and Experimental Design: Eight multiparous Holstein cows (676 ± 57 kg BW; 121 ± 17 DIM) were used in a replicated 4 x 4 Latin square design with 21-d periods and 4 dietary treatments. Four cows in 1 Latin square were fitted with permanent ruminal cannulae and were used in a metabolic study to investigate dietary effects on ruminal fermentation patterns and total tract diet digestibility. Cows were housed in individual tie-stalls and had free access to drinking water throughout the trial. Animals were cared for and handled in accordance with the Canadian Council on Animal Care regulations and the University of Saskatchewan Animal Care Committee approved their use for this experiment (UCACS Protocol No. 20040048).

1.3. Experimental Treatments, Feeding Management and Sample Collection: The 4 dietary treatments examined were different cereal grains as the major source of starch, with the concentrate portion of the diet containing barley, corn, wheat, or oats. All cereal grains were dry rolled. Experimental diets contained between 28 and 31% of cereal grain as the major source of starch. The ingredient composition and chemical analysis of the experimental diets is shown in Table 1. Barley, corn, wheat, and oats were selected because dairy cow diets in western Canada and the USA typically contain any 1 or combinations of these cereal grains as the principal source of energy. Additionally, starch content and the rates and extents of ruminal starch degradation differ with the species of cereal grain. The main protein sources for the experimental diets were whole canola seed, canola meal, wheat distillers dried grains and corn gluten meal (Table 1). Whole canola seed was added to the concentrate such that experimental diets would contain 5 to 6% fat,

on a DM basis. The forage to concentrate ratio of the diets was 50:50. The forage component of the diet was a mixture of barley silage and chopped alfalfa hay. The diets were formulated to be isonitrogenous at 2.72% N (17% CP). During each data collection period, particle size distribution was determined for the forage mixture using the Penn State Particle Separator (**PSPS**) as described by Heinrichs (1996). The PSPS used was equipped with 3 screens (19.0, 8.0 and 1.18 mm) and a bottom pan. Briefly, approximately 150 to 200 g of the forage mixture was placed on the top screen of the PSPS. The PSPS was shaken as described by Heinrichs (1996). As-fed forage fractions retained on each screen and the bottom pan were then weighed to determine particle size distribution.

Each 21-d experimental period consisted of 14 d of dietary adaptation and 7 d (d 15 to 21) for sample and data collection. Experimental diets were fed twice daily at 0800 and 1530 h as TMR for *ad libitum* intake. During the 7-d sample and data collection period, individual cow feed intake was recorded daily. Samples of TMR and orts were collected daily, stored at -20°C, and composited per cow for each experimental period. Composite samples of orts were based on daily amounts of orts for each cow. After the experiment, pooled samples of TMR and orts were dried at 55°C in an oven for 48 h, ground through a 1-mm screen using a Christy-Norris mill (Christy and Norris Ltd., Chelmsford, England), and analyzed for DM, OM, ether extract, Kjeldahl N (AOAC, 1990), ADF (Van Soest et al., 1991), NDF with heat-stable α-amylase and sodium sulfite (Van Soest et al., 1991). Starch concentration of TMR, orts and fecal samples was analyzed using a starch assay kit (Megazyme International Ireland Ltd., Wicklow, Ireland; McCleary et al., 1994).

Cows were milked twice daily at 0500 and 1500 h, and milk weights were recorded during the 7-d data collection period. Milk production was converted to 3.5% fat-corrected milk (FCM) as (0.434 X kg of milk) + (16.216 X kg of milk fat). On d 17, 18 and 19 of each experimental period, milk samples were collected from morning and afternoon milkings into plastic vials that contained

a preservative (2-bromo-2-nitropropane-1-2-diol). Milk samples were then pooled daily based on milk yield. Pooled samples were immediately submitted to the Provincial Milk Testing Laboratory (Saskatchewan Agriculture, Food and Rural Revitalization, Regina, SK) for compositional analysis. Milk samples were analyzed for CP, lactose and fat using a near infrared analyzer (Foss System 4000, Foss Electric, Hillerod, Denmark) according to AOAC (1990).

Blood samples were collected at 4 h post-feeding on d 19 and 20 of the experimental period from the coccygeal vein of each animal using 2.5-cm, 20-gauge needles, and collected into 10-ml heparin-containing tubes (Becton Dickinson, Rutherford, NJ). Plasma was prepared immediately after collection by centrifugation of blood at 1,000 x *g* for 15 min and then stored at -20°C until further analysis. Plasma urea-N (**PUN**) was determined colorimetrically using the diacetyl monoxime method (Procedure No. 0580; Stanbio Laboratory, Boerne, TX). Plasma glucose concentration was measured with a glucose oxidase method (Procedure No. 1070; Stanbio Laboratory, Boene, TX).

1.4: Ruminal Fermentation Characteristic, Total Tract Diet Digestibility and N Balance: Ruminal fermentation characteristics and total tract diet digestibility were determined using the ruminally-cannulated cows. On d 18 of each experimental period, 1,000 mL of ruminal contents were collected by manually taking 250 mL of ruminal contents from the cranial ventral, caudal ventral, central, and cranial dorsal rumen through the cannula at 0 (just before the morning feeding), 2, 4 and 6 h after feeding. Ruminal fluid samples were obtained by straining ruminal contents through 4 layers of cheesecloth. Ruminal fluid pH was immediately determined using a Model 265A portable pH meter (Orion Research Inc., Beverly, MA). A 5-ml sub-sample of strained ruminal fluid was mixed with chilled 25% meta-phosphoric acid (H_2PO_4) and stored at -20°C for later determination of VFA. Another 5-ml sub-sample was mixed with 1% H_2SO_4 and stored at -20°C for later determination of ammonia-N (NH_3-N). At the end of the trial, frozen

ruminal fluid sub-samples were thawed at room temperature and then centrifuged at 20,000 x g for 20 min. Ruminal VFA were separated and quantified by gas chromatography (Varian 3700; Varian Specialties Ltd., Brockville, ON) with a 15-m (0.53-mm i.d.) fused silica column (DB-FFAP column; J and W Scientific, Folsom, CA). Ammonia content of ruminal samples was determined using the method described by Weatherburn (1967) modified to use a microtiter plate reader.

Total tract nutrient digestibility was determined by total collection of feces and urine between d 17 and d 21 of each experimental period. Feces were collected into large steel trays which were positioned over the gutter behind each stall. Total daily fecal output for each cow was mixed thoroughly before a 2.5% sub-sample was taken and stored at -20°C. At the end of the trial, frozen fecal sub-samples were thawed, dried at 55°C, and then ground through a 1-mm screen using a Christy-Norris mill (Christy and Norris Ltd., Chelmsford, England). Ground fecal samples were then composited per cow for each experimental period and analyzed for OM, CP, EE, starch, ADF, and NDF using the methods already described for pooled TMR and orts samples.

Total urine output was collected using indwelling Bardex Foley bladder catheters (26 Fr, 75 cc ribbed balloon, lubricious-coated; C. R. Bard Inc., Covington, GA). Bladder catheter insertion was conducted as described by Crutchfield (1968). Catheters were inserted at 0900 h on d 16, and were then connected to urine collection tubing at 0900 h on d 17. Urine was collected into 20-L Carboy polyethylene containers into which 150 mL of concentrated hydrochloric acid had been added in order to achieve urine pH of less than 3. The acidification of urine was necessary to prevent microbial degradation and the loss of volatile NH_3-N. Daily urinary output was weighed, mixed thoroughly and 5% of the output was drawn, pooled for each cow during each collection period and stored at -20°C until analyzed for total N. Urine N was determined by the macro-Kjeldahl procedure (AOAC, 1990) using a Kjeltec 2400 auto-analyzer (FOSS Analytical, Hilleroed, Denmark). In addition, a 2-mL aliquot of urine was diluted with 8 mL of distilled water

and stored at -20°C for later analysis. Diluted urine samples were pooled per cow according to daily urine output for each period and analyzed for allantoin by the colorimetric method described by Chen and Gomes (1992). Uric acid was determined in the same samples according to Fossati et al. (1980), using a commercial kit (Stanbio Uric acid Liquicolor®; Stanbio Laboratory, Boene, TX). Total purine derivative (PD; i.e., allantoin + uric acid) excretion per day was used to estimate microbial N yield as described by Chen and Gomes (1992), with the exception that a constant endogenous PD fraction of 56.86 mmol/d was used in the calculation (Gonzalez-Ronquillo et al., 2003). Nitrogen retained was calculated as intake N - fecal N - urinary N - milk N. Milk N was determined as milk CP ÷ 6.38.

1.5. Statistical Analysis: Data on DMI, milk yield and composition, plasma urea nitrogen and glucose were analyzed as a replicated 4 x 4 Latin square using the Proc Mixed procedure of SAS (SAS User's Guide, 2004) using the following model: $Y_{ijkl} = \mu + S_i + P_{j(i)} + C_{k(i)} + T_l + \epsilon_{ijkl}$, where Y_{ijkl} is the dependent variable, μ is the overall mean, S_i is the fixed effect of square i, $P_{j(i)}$ is the fixed effect of period j (within square i), $C_{k(i)}$ is the random effect of cow k (within square i), T_l is the fixed effect of treatment l, and ϵ_{ijkl} is the random residual error. For urinary PD fractions and N balance data, the following model was used: $Y_{ijkl} = \mu + P_i + C_j + T_k + \epsilon_{ijk}$, where Y_{ijk} is the dependent variable, μ is the overall mean, P_i is the fixed effect of period i, C_j is the random effect of cow j, T_k is the fixed effect of treatment k, and ϵ_{ijk} is the random residual error. Measurements of ruminal pH, ruminal VFA and NH_3-N concentrations were analyzed as repeated measures using PROC MIXED procedure (SAS Institute, 2004). The statistical model used included period, treatment, time, and treatment x time interaction as fixed effects, and cow as a random effect. The subject of the repeated measurement was defined as cow (period x treatment). The Kenward-Roger option was used to estimate denominator degrees of freedom. The nine covariance structures that were tested were: Autoregressive 1 (AR [1]); Compound symmetry (CS); Heterogeneous

autoregressive (ARH [1]); Unstructured (UN); Variance components (VC); Toeplitz (Toep); Heterogeneous compound symmetry (CSH); Heterogeneous Toeplitz (Toeph); and Simple. The covariance structure with the lowest (closest to zero) Akaike's Information Criterion values was selected (Littell et al., 1996). Least square means were separated using Bonferoni's procedure in SAS (2004). Treatment effects were declared significant at $P \leq 0.05$, and tendencies from $P > 0.05$ to ≤ 0.10. The P values that are indicated in Tables 2, 4, 5 and 6 refer to overall diet effects. Where diet effects were or tended to be significant, the P values that are indicated in the Results and Discussion refer to mean separation.

2. Experiment 2:

2.1. ***Objectives:*** The objective of this study was to determine how interactions between method of barley grain processing (dry-rolling vs pelleting) and source of supplemental fat in the diet (whole canola seed vs. whole flaxseed) alter urea-N transfer to the GIT and its utilization in lactating dairy cows.

2.2. Animals and Experimental Design: Four Holstein cows (656.3 ± 27.7 kg BW; 79.8 ± 12.3 DIM) were used in a 4 x 4 Latin square design with 28-d periods and a 2 x 2 factorial arrangement of dietary treatments. Each experimental period consisted of 14 d of dietary adaptation and 14 d of data collection. Throughout the experiment, cows were housed individually in tie-stalls at the Greenbrae Dairy Research Facility (University of Saskatchewan). Cows were cared for and handled in accordance with the Canadian Council of Animal Care regulations, and their use in the experiment was approved by the University of Saskatchewan Animal Care Committee (UCACS Protocol No. 20040048).

2.3. Experimental Treatments and Feeding Management: Experimental treatments were combinations of barley grain processing (dry-rolling or pelleting) and two sources of dietary

supplemental fat (whole canola seed and whole flaxseed) as follows: a) dry-rolled barley + whole canola seed; b) dry-rolled barley + whole flaxseed; c) pelleted barley + whole canola seed; and d) pelleted barley + whole flaxseed. The diets were formulated to be isonitrogenous and isolipidic. Complete ingredient and chemical composition of experimental diets are presented in Table 7. Dry-rolled barley was prepared by passing whole barley grain through large rollers (23 x 58 cm). For pelleting, whole barley grain was ground through a 6.25 mm screen in a hammer-mill and then pelleted using a California pellet mill. Both dry-rolled and pelleted barley were from the same source. Experimental diets were fed twice daily at 0900 and 1600 h as total mixed rations (TMR) for ad libitum intake. The forage:concentrate ratio of the TMR was 50:50. The forage component of the TMR was a mixture of barley silage and chopped alfalfa hay. Barley silage contained 35.5% DM and its chemical composition (DM basis) was: OM, 90.9%; CP, 11.3%; NDF, 54.7%; ADF, 35.8%; and EE, 3.42%. Whole canola seed or whole flaxseed was added such that experimental TMR contained approximately 5.3% total fat.

2.4. Sample Collection: During the 14-d data collection period (d 15 to d 28), feed intake was recorded daily, TMR samples were collected three times weekly, and orts were collected daily and composited by cow proportionally to the weight of feed refused each day and stored at -20°C for later analysis. Cows were milked twice daily at 0500 and 1500 h, and milk weights were recorded during the 14-d data collection period. Milk samples were collected into plastic vials with 2-bromo-2-nitropropane-1-2-diol as a preservative on d 23, 25, and 26 from morning and afternoon milking. Daily milk samples from the two milkings for each cow were pooled based on milk yield from each milking. Pooled milk samples were sent to the Provincial Milk Testing Laboratory (Saskatchewan Agriculture, Food and Rural Revitalization, Regina, SK) for milk protein and fat analyses using a near infrared analyzer (Foss System 4000, Foss Electric, Hillerod, Denmark) according to AOAC (1990).

On d 14 of each experimental period, cows were fitted with temporary vinyl catheters (0.86 mm I.D. x 1.32 mm O.D.; Scientific Commodities Inc., Lake Havasu City, AZ) in the right and left jugular veins to allow for simultaneous isotope infusion and blood sampling. Urea-N transfer to the GIT and whole-body N balance were determined between d 15 and 19 as described by Lobley et al. (2000), except that urine was collected using bladder catheters. Briefly, background samples of urine and feces were collected on d 14 to measure ^{15}N natural abundance. Starting on d 15, double-labeled urea ([$^{15}N^{15}N$]-urea, 99.8 atom % ^{15}N; Cambridge Isotope Laboratories, Andover, MA) prepared in 0.15 M sterile saline was infused continuously into the jugular vein at a rate of 0.384 mg/d for 96 h. Total collection of feces and urine were conducted between d 15 and d 19 of each experimental period. Feces were collected into large steel trays which were positioned over the gutter behind each stall. Daily fecal output for each cow was determined by weighing and feces were then mixed thoroughly before 2.5% of daily output was sampled and stored at -20°C for later chemical analysis. During isotope infusion, fecal grab samples were collected daily at 0900 h just before the morning feeding and stored at -20°C until analyzed for ^{15}N enrichment.

Total urine output was collected using indwelling Bardex Foley bladder catheters (26 Fr, 75 cc ribbed balloon, lubricious-coated; C. R. Bard Inc., Covington, GA). Catheters were inserted at 0900 h on d 14, and were then connected to urine collection tubing when isotopic infusions were initiated at 0900 h on d 15. Urine was collected into 20-L Carboy polyethylene containers into which 150 mL of concentrated HCl had been added in order to achieve urine pH of less than 3. The acidification of urine was necessary to prevent microbial degradation and the loss of volatile NH_3-N. Daily urinary output was weighed, mixed thoroughly and a 5% sub-sample of the daily output was drawn, pooled for each cow during each collection period and stored at -20°C until analyzed for total N. A 50-mL sample of urine was also collected daily during isotope infusion directly from the urine collection tubing and stored at -20°C until analyzed for proportions of [$^{15}N^{15}N$]-,

[$^{14}N^{15}N$]- and [$^{14}N^{14}N$]-urea. In addition, a 2-mL aliquot of urine was diluted with 8 mL of distilled water and stored at -20°C for later determination of urea-N and purine derivatives. Blood samples were collected daily during isotope infusion from the contra-lateral jugular vein into sodium heparin-coated tubes just before the morning feeding. Blood samples were centrifuged at 1,500 x *g* for 15 minutes at 4°C and the plasma obtained was stored at -20°C until later analysis for urea-N.

Starting on d 23 of each experimental period, ruminal pH was measured continuously for 3 consecutive days using the Lethbridge Research Center Ruminal pH Measurement System (Dascor, Escondido, CA) as described by Penner et al. (2006). On d 27 through d 28 of each experimental period, 1000 mL of ruminal contents were collected by manually taking 250 mL of ruminal contents from the cranial ventral, caudal ventral, central, and cranial dorsal rumen through the cannula just before the morning feeding at 0900 h, and then at 4-hourly intervals over a 24-h feeding cycle. Ruminal fluid samples were obtained by squeezing ruminal contents through four layers of cheesecloth. Two 5-mL aliquots of strained ruminal fluid were mixed with 1 mL of metaphosphoric acid (25% wt/vol) and 1 mL of 1% H_2SO_4 and stored at -20°C for later determination of ruminal VFA and NH_3-N, respectively.

2.5. Sample Analyses: At the end of the trial, frozen TMR, orts and fecal sub-samples were thawed overnight at room temperature and were analyzed for DM by drying in an oven at 60°C for 48 h (AOAC, 1990). Dried TMR, orts and feces were then ground through a 1-mm screen using a Christy-Norris mill (Christy and Norris Ltd., Chelmsford, England) and analyzed for OM by combustion in a muffle furnace at 550°C for at least 8 h, CP by the macro-Kjeldahl procedure using a Kjetec 2400 auto-analyzer to determine N content, ether extract and ash (AOAC, 1990). Additionally, total N in pooled urine samples was also determined by the macro-Kjeldahl procedure. Neutral detergent (NDF) and acid detergent (ADF) fiber were analyzed according to the

procedure of Van Soest et al. (1991). Sulfite and heat-stable alpha-amylase were used for NDF analysis.

Daily urine samples that were diluted at collection were pooled per cow proportionally to daily urine output for each period and analyzed for allantoin according to Chen and Gomes (1992). Uric acid was measured according to Fossati et al. (1980) using a commercial kit (Stanbio Uric acid Liquicolor®; Stanbio Laboratories). Total purine derivative (**PD**; i.e., allantoin + uric acid) excretion per day was used to estimate microbial N yield as described by Chen and Gomes (1992) with the exception that a constant endogenous PD fraction of 56.86 mmol/d was used in the calculation (Gonzalez-Ronquillo et al., 2003). Plasma urea-N and urinary urea-N were determined by the diacetyl monoxime method of Marsh et al. (1957) using a commercial kit (Stanbio Urea Nitrogen Kit, Stanbio Laboratories).

To determine the proportions of [^{15}N^{15}N]-, [^{14}N^{15}N]- and [^{14}N^{14}N]-urea in urinary urea, an aliquot of urine that contained 1.5 mg of urea-N was passed through pre-packed cation exchange resin columns (AG-50W-×8 Resin, 100-200 mesh, H^+ form; Biorad, Richmond, CA) as described by Archibeque et al. (2001). After the urine had been applied to the column, 7 mL of N-free water was then applied to the columns, with the eluate discarded. Urea was then eluted by applying 20 mL of N-free water to the columns, which was collected into test tubes. The eluate was air-dried at 60°C, and urea was quantitatively transferred into 17- x 60-mm borosilicate glass tubes using three, 1-mL rinses of N-free water. The urea samples were then freeze-dried and the proportions of [^{15}N^{15}N]-, [^{14}N^{15}N]- and [^{14}N^{14}N]-urea in urinary urea were analyzed by isotope ratio-mass spectrometry (Lobley et al., 2000) at the N-15 Analysis Laboratory, University of Illinois at Urbana-Champaign. Under the conditions of this assay, [^{14}N^{14}N]-, [^{14}N^{15}N]-, and [^{15}N^{15}N]-urea molecules should yield ions with mass/charge (**m/z**) values of 28, 29, and 30, respectively. To account for non-monomolecular reactions, standards which were prepared from

[$^{15}N^{15}N$]-urea (99.8 atom % ^{15}N) and [$^{14}N^{14}N$]-urea (natural abundance urea; 0.364 atoms % ^{15}N) were also analyzed and the necessary corrections for [$^{14}N^{15}N$]-urea that is produced by non-monomolecular reactions were then made (Lobley et al., 2000). Fecal grab samples that were collected daily during the total collection period were thawed overnight at room temperature and were analyzed for DM by drying in an oven at 60°C for 48 h (AOAC, 1990). Dried feces were then ground through a 1-mm screen using a Christy-Norris mill (Christy and Norris Ltd., Chelmsford, England) and subsequently ground to a fine powder using a rotating ball mill. Finely-ground fecal samples were then analyzed for total ^{15}N enrichment by combustion to N_2 gas in an elemental analyzer and continuous flow isotope ratio-mass spectrometry as described by Lobley et al. (2000).

Ruminal fluid samples were thawed at room temperature, centrifuged at 18,000 x *g* for 15 min and filtered through a 0.45-µm membrane. A 0.9-mL portion of the filtered supernatant was mixed with 0.1 mL of 10 mg/mL crotonic acid as an internal standard. Ruminal VFA were separated and quantified by gas chromatography (Agilent 6890, Mississauga, ON) as described by Erwin et al. (1961). Similarly, ruminal fluid samples for ruminal NH_3-N determination were thawed, centrifuged for 10 min at 18,000 x *g* to obtain a clear supernatant, and then analyzed using a phenol-hypochlorite assay (Broderick and Kang, 1980).

2.6. Calculation of Urea-N Kinetics: Urea-N kinetics was calculated according to the model of Lobley et al. (2000), using urinary ^{15}N enrichment of [$^{15}N^{15}N$], [$^{14}N^{15}N$] and [$^{14}N^{14}N$] urea and total ^{15}N excretion in feces. In this model, a portion of urea-N synthesized in the liver (urea-N entry rate, **UER**) is lost via the urine (urinary urea-N elimination, **UUE**), and the remainder enters the GIT (GIT entry rate, **GER**). The urea-N entering the GIT (i.e., GER) undergoes bacterial degradation liberating NH_3. A portion of this NH_3 is excreted in feces (urea-N in feces, **UFE**), some is reabsorbed into portal blood and it re-enters the ornithine cycle in the liver (**ROC**), and the

remainder is used for anabolic purposes i.e., synthesis of microbial protein (urea-N utilized for anabolism, **UUA**) (Lobley et al., 2000).

2.7. Statistical Analysis: All data were analyzed using Proc Mixed (SAS, 2004). The statistical model that was used for DM intake, N balance and nutrient digestibilities, urea-N kinetics and PD excretion included the following terms: method of barley processing and source of supplemental fat, which were considered fixed, the interaction between method of barley processing and source of supplemental fat, the random effects of period and cow, and the residual error. Data on milk yield, milk composition, ruminal pH, and ruminal concentrations of VFA and NH_3-N were analyzed accounting for repeated measures as recommended by Wang and Goonewardene (2004) for the analysis of animal experiments. Data for these repeated measurements were analyzed by including in the model a REPEATED model statement, as well as terms for time (hour or day), and interactions (method of barley processing x time, source of supplemental fat x time, and time x method of barley processing x source of supplemental fat) in the model described previously. When processing x time or oilseed x time interactions were significant , the slice option for the LSMEANS statement in PROC MIXED was used to determine which time period means were different. Significance for all models was declared at $P \leq 0.05$, and trends are discussed for $0.05 < P \leq 0.10$. When there was a significant interaction between method of barley processing and source of supplemental fat, least square means were separated by Tukey's HSD test (SAS, 2004).

3. Experiment 3:

3.1. Objectives: The objective of this study was to determine how interactions between dietary content of N and RDP alter urea-N transfer to the GIT and the utilization of this recycled urea-N in growing beef heifers.

3.2. Animals and Experimental Design: Four growing beef heifers (437 kg BW) surgically fitted with ruminal (10 cm diameter opening, Bar Diamond, Parma, ID) and duodenal T-type cannulae (placed proximal to the common bile and pancreatic ducts, approximately 10 cm distal to the pylorus) were used. The placement of cannulas enabled the collection of both ruminal and duodenal contents. The animals were housed in individual pens on rubber mats in the Livestock Research Building at the Department of Animal and Poultry Science at the University of Saskatchewan. The experimental design was a 4 × 4 Latin square with a 2 × 2 factorial arrangement of dietary treatments. Animals were cared for and handled in accordance with the Canadian Council on Animal Care regulations, and the University of Saskatchewan Animal Care Committee approved their use for this experiment.

3.3. Experimental treatments, feeding management and sample collection: The 4 dietary treatments were formulated by combining 2 factors, each with 2 levels. The dietary factors studied were: 1) 2 levels of crude protein (CP; 10 vs. 13%) and 2 levels of ruminally-degradable protein (RDP; 64.5 vs. 71%; % of CP). Diets were formulated to meet beef NRC (1996) nutrient requirements. The composition and nutrient content of experimental diets is shown in Table 14.

Each 23 d experimental period consisted of 14 d of dietary adaptation (d 1 to 14) and 8 d for data collection (d 15 to 23). Experimental diets were fed twice daily at 0800 and 1600 h as a pelleted ration. From d 18 to d 23 the feed offered and orts remaining were weighed daily in order to calculate feed intake and sub-samples were taken, stored at -20°C, composited per animal for each experimental period, and then ground through a 1-mm screen using a Christy-Norris mill (Christy and Norris Ltd., Chelmsford, England). Feed samples were subsequently analyzed for DM by drying in an oven at 135°C for 2 h (AOAC, 1990; ID no. 930.15), OM by ashing at 550°C for at least 8 h (AOAC, 1990; ID no. 942.05), CP using the macro-Kjeldahl procedure (AOAC, 1990; ID

no. 976.05), ether extract (AOAC, 1990; ID no. 920.39), ADF (AOAC, 1990), and NDF (Van Soest et al., 1991). Amylase and sodium sulfite were used for NDF determination.

Blood samples were collected via jugular catheters every 4 h for 24 h (0800 h on d 21 to 0600 h on d 22), into 10-ml heparin-containing tubes (Becton Dickinson, Rutherford, NJ). Plasma was prepared by centrifugation of blood at 1,500 x *g* at 4°C for 15 min and then stored at -20°C until further analysis for plasma urea-N. Frozen blood plasma samples were thawed and composited per animal for each experimental period. Plasma urea-N was determined colorimetrically using the diacetyl monoxime method of Marsh et al. (1957) using a commercial kit (Stanibo Urea Nitrogen Kit, Procedure No. 0580; Stanbio Laboratories, Texas, USA).

3.4. Measurement of Digesta Flow Rate: Digesta flow rate to the duodenum was measured using $YbCl_3.6H_2O$ (VWR, Edmonton, AB, Canada) as a marker. $YbCl_3.6H_2O$ was dissolved in distilled water and infused into the rumen at a constant rate of 2.2 g of Yb per day (Reynal et al, 2005) in 2 L of solution. The marker was continually infused into the rumen via the rumen cannula for 7 days (d 15-d 22) using a peristaltic pump (Watson and Marlow, Cornwall, UK. Model: 205U). Prior to the start of the infusions (on d 15), a priming dose equal to one-half of the daily dose of the marker was administered. Before starting the infusion of the marker (d 15), a sample of rumen contents (500 ml), duodenal digesta (500 ml) and a fecal grab sample were collected from each animal to determine the background levels of Yb. Duodenal samples were collected every 2 h for 24 h (0800 h on d 21 to 0600 h on d 22) and stored at -20°C until further analysis for Yb level and ^{15}N enrichment. Duodenal samples were thawed and composited per animal for each experimental period. Samples were subsequently freeze-dried and ground to 1 mm using a coffee grinder. Samples for ^{15}N enrichment analysis were further ground using a ball mill and the ammonia-N was volatilized (Reynal et al, 2005) prior to ^{15}N enrichment analysis (Stable Isotope Facilities, University of Saskatchewan, Canada).

3.5. Rumen Fermentation, Whole-Tract Digestibility, Nitrogen Balance and Quantification of Microbial Protein Synthesis: Urea-N recycling to the rumen, total N balance, and quantification of microbial protein synthesis were measured by jugular infusions of [$^{15}N^{15}N$]urea (d 18 to d 22) and total collection of feces and urine (d 18 to d 23), as described by Lobley et al. (2000) and collection of rumen, duodenal and fecal grab samples every 2 h (0800 h on d 21 to 0600 h on d 22). Heifers were fitted with jugular catheters on d 17 for [$^{15}N^{15}N$]urea infusion and blood collection. Urine, fecal, and duodenal samples were collected on d 18, prior to the start of [$^{15}N^{15}N$]urea infusions at 0800 h, in order to determine the natural abundance of ^{15}N (background sample). [$^{15}N^{15}N$]urea was infused intravenously from 0800 h on d 18 to 0800 h on d 22 at a rate of 220 mg/d of [$^{15}N^{15}N$]urea (99.8 atom % ^{15}N; Cambridge Isotope Laboratories, Andover, MA) in 2 L of saline solution using a peristaltic pump (Watson and Marlow, Cornwall, UK. Model: 205U).

Total urine output was collected using indwelling Bardex Foley bladder catheters (26 Fr, 75 cc ribbed balloon, lubricious-coated; C. R. Bard Inc., Covington, GA). Bladder catheter insertion was conducted as described by Crutchfield (1968). Catheters were inserted on d 17, and were connected to urine collection containers on d 18. This was done to allow heifers to adapt to having the catheter inserted in their bladders before urine collection commenced. Urine was collected into 20-L Carboy polyethylene containers under acidic conditions. Urine was acidified (to achieve pH < 3) daily with 80-ml of concentrated HCl (VWR Scientific, Mississauga, ON) which was added to urine collection containers to prevent loss of volatile NH_3-N and microbial degradation. Total daily urine output for each heifer was weighed, mixed thoroughly and a 20% sub-sample was taken and stored frozen at -20°C. Urine samples were thawed and composited per animal for each experimental period for the determination of total N using the macro-Kjeldahl procedure (AOAC, 1990; ID no. 976.05). From d 19 to d 23 a 50-mL urine sample was collected daily directly from the bladder catheters at 0800 h by diverting the bladder catheter tube from the daily collection

container into another container. These samples were frozen at -20°C and later analysed to determine ^{15}N enrichment of [$^{15}N^{15}N$]urea, [$^{14}N^{15}N$]urea and [$^{14}N^{14}N$]urea in the urine (Archibeque et al, 2001). Urinary urea was isolated by passage of an aliquot of urine containing 1.5 mg of urea N through 2 mL of a cation exchange resin column (AG-50W-×8 Resin, 100–200 mesh, H^+ form; Biorad Laboratories, Richmond, CA). After application of the urine sample to the column, the column was washed with 7 mL of N-free water, which was subsequently discarded. The urea was then eluted by 20 mL of N-free water into test tubes. Samples were air-dried at 60°C and then were quantitatively transferred to 17 × 60-mm borosilicate glass tubes with three, 1-mL rinses of N-free water. The urea samples were then freeze-dried and the proportions of [$^{15}N^{15}N$]urea, [$^{14}N^{15}N$]urea and [$^{14}N^{14}N$]urea in urinary urea were analysed by isotope ratio-mass spectrometry (Lobley et al., 2000) at the N-15 Analysis Laboratory, University of Illinois at Urbana-Champaign, with the necessary corrections for [$^{14}N^{15}N$]urea that is produced by non-monomolecular reactions (Lobley et al., 2000).

From d 19 to d 23, 2 mL of urine, from the bladder catheter, was collected and added to 8-mL of distilled water and stored at -20°C for later determination of urinary urea-N. Urine samples were thawed and composited per animal for each experimental period. Urinary urea-N was determined colorimetrically in diluted and composited samples, using the diacetyl monoxime method of Marsh et al. (1957) using a commercial kit (Stanbio Urea Nitrogen Kit, Procedure No. 0580; Stanbio Laboratories, Texas, USA). Microbial N was estimated based on excretion of purine derivatives (uric acid and allantoin) in diluted urine samples. Uric acid was determined using a quantitative enzymatic colorimetric method in diluted and composited samples (Stanbio Uric Acid Liquicolor Kit, Procedure No. 1045; Stanbio Laboratories, Texas, USA). Allantoin was determined by a colorimetric method (Chen and Gomes, 1995).

Total feces were collected from experimental animals for 5 d (d 19 to d 23 of each experimental period). Total daily fecal output for each heifer was mixed thoroughly, quantitatively transferred into a pre-weighed plastic container and weighed. A 10% sub-sample was taken daily and stored at -20°C. At the end of the trial, fecal sub-samples were subsequently dried at 55°C for 96 h, ground through 1-mm screen using a Christy-Norris mill (Christy and Norris Ltd., Chelmsford, England) and ground samples were then composited per animal for each experimental period. Composited feces were analyzed for DM by drying in an oven at 135°C for 2 h (AOAC, 1990; ID no. 930.15), OM by ashing at 550°C for at least 8 h (AOAC, 1990; ID no. 942.05), CP using the macro-Kjeldahl procedure (AOAC, 1990; ID no. 976.05), ether extract (AOAC, 1990; ID no. 920.39), ADF (AOAC, 1990), and NDF (Van Soest et al., 1991). Amylase and sodium sulfite were used for NDF determination. Daily fecal grab sample were collected (d 17 to d 22) and stored separately at -20°C. Samples were thawed and dried at 55°C for 96 h, and subsequently ground through a 1-mm screen using a Christy-Norris mill (Christy and Norris Ltd., Chelmsford, England). Samples were finely ground using a ball mill and analysed for ^{15}N enrichment on individual samples (Stable Isotope Facilities, University of Saskatchewan, Canada).

Samples of rumen contents were collected every 4 h for 24 h (0800 h on d 21 to 0600 h on d 22) for volatile fatty acids (VFA), ammonia-nitrogen (NH_3-N), and osmolality analysis, rumen pH measurement and microbial protein production. Ruminal contents (250 mL) were collected, via the rumen cannula, from 4 different regions (cranial ventral, caudal ventral, central, and cranial dorsal). After thorough mixing, a 500-mL portion was sieved through 4 layers of cheesecloth. Ruminal fluid pH was immediately determined using a Model 265A portal pH meter (Orion Research Inc., Beverly, MA). A 5-mL sub-sample of strained ruminal fluid was mixed with chilled 25% meta-phosphoric acid (H_2PO_4) and stored at -20°C for later determination of VFA concentrations. Frozen rumen fluid samples were thawed and centrifuged at 18,000 × g for 15

minutes and filtered through a 0.45-μm membrane. A sub-sample (0.9 mL) of supernatant was pipetted into a clean, dry vial. Crotonic acid was used as an internal standard with 1 mg/mL added to each vial before analysis by gas chromatography (Erwin et al, 1961; Agilent 6890, Mississauga, Ontario, Canada). Another 5-mL sub-sample was mixed with H_2SO_4 and stored at -20°C for later determination of ammonia-N. Briefly, samples were thawed and centrifuged at 18,000 × *g* for 10 minutes and the supernatant was analysed using a phenol-hypochlorite assay (Broderick and Kang, 1980). A 15-mL sub-sample was collected and stored at -20°C for later determination of osmolality. Samples were thawed, centrifuged at 3,000 × *g* for 15 minutes then analysed by vapor pressure (Wesco Vapro 5520, Logan, Utah).

The solid portion of rumen digesta from the cheesecloth was thoroughly blended with 400 mL of saline solution and then sieved through four layers of cheesecloth. The resulting fluid was mixed with the previously strained rumen fluid and then stored on ice until processing. The rumen fluid was centrifuged at 1,000 × *g* for 6 minutes to remove protozoa and feed particles. The supernatant was decanted and then centrifuged at 20,000 × *g* for 30 minutes and the resulting pellet was frozen at -20°C for later analysis (adapted from Reynal et al. 2005). Bacterial pellets were composited per experimental period for each animal. The composited samples were freeze-dried, ground to 1-mm using a coffee grinder then finely ground using a ball mill in preparation for analysis of ^{15}N enrichment by isotope-ratio mass spectroscopy (Stable Isotope Facilities, University of Saskatchewan, Canada).

3.6. Calculation of Urea-N Kinetics: Urea-N kinetics was calculated according to the model of Lobley et al. (2000), using urinary ^{15}N enrichment of [$^{15}N^{15}N$], [$^{14}N^{15}N$] and [$^{14}N^{14}N$]urea and total ^{15}N excretion in feces. In this model, a portion of urea-N synthesized in the liver (urea-N entry rate, **UER**) is lost via the urine (urinary urea-N elimination, **UUE**), and the remainder enters the GIT (GIT entry rate, **GER**). The urea-N entering the GIT (i.e., GER) undergoes bacterial degradation

liberating NH_3. A portion of this NH_3 is excreted in feces (urea-N in feces, **UFE**), some is reabsorbed into portal blood and it re-enters the ornithine cycle in the liver (**ROC**), and the remainder is used for anabolic purposes i.e., synthesis of microbial protein (urea-N utilized for anabolism, **UUA**) (Lobley et al., 2000).

3.7. Statistical Analysis: All data were analyzed using analysis of variance **(ANOVA)** as a 4 × 4 Latin square design; digestibility and N balance data were analyzed using the Proc Mixed procedure of SAS, whereas urea-N recycling kinetics were analyzed using the Proc GLM procedure of SAS (SAS Inst. Inc., Cary, NC) with heifer and period as the random effects. The models included the following independent variables: period, level of CP, level of RDP, and the level of CP × level of RDP interaction. When significant treatment effects were found, means were compared using the Tukey-Kramer multiple comparison test. Rumen fermentation characteristics (pH, ammonia-N, osmolality and FVA concentration) were analyzed using the Proc Mixed repeated measures procedures of SAS. Treatment differences were considered significant when $P < 0.05$ and tendencies are discussed when $P < 0.10$. *In situ* rumen degradation characteristics were analyzed using the NLIN procedure (SAS, 2004) using iterative least squares regression (Gauss-Newton method) as described by Yu at al. (2003).

D. RESULTS

1. EXPERIMENT 1:

1.1. Diet Characteristics: The ingredient composition and chemical analysis of experimental TMR are presented in Table 1. Across diets, the DM, CP, ADF, NDF, and starch contents were (mean ± SE) 54.6 ± 0.4, 17.4 ± 0.3, 26.7 ± 0.6, 33.6 ± 1.4 %, and 19.7 ± 3.3 (DM basis), respectively (Table 1). The starch content of the oats-based diet was numerically lower than that of the barley-, corn-, and wheat-based diets (Table 1), which is a reflection of differences in starch contents of the original cereal grains. It is noteworthy that the lower starch content of the oats-based diet did not compromise production performance when compared to the diets with numerically higher starch contents. Average dietary ADF and NDF contents were higher than or in the high end of NRC (2001) minimum recommendations of 17 to 21% and 25 to 33%, respectively, for the maintenance of proper ruminal function. This was related to higher than anticipated ADF and NDF concentrations of the barley silage used in this study. Diets formulated to contain NDF above the minimum NRC (2001) recommendations can limit DM intake; however, in the present study, average DM intake was 25.4 kg/d, or approximately 3.8% of mean BW, and this falls within the expected range for dairy cows producing >35 kg/d of milk (NRC, 2001). Averaged across treatments, dietary fat was 5.5 ± 0.2 % on a DM basis, which falls within the desired range of 5 to 6% total dietary fat. Fat levels exceeding 6 to 7% reduce fiber digestion and, consequently, lower DM intake in dairy cows (NRC, 2001), hence it was desired to maintain total dietary fat below 6% of DM. Percentages (as fed basis) of the forage mixture retained on the 19.0-, 8.0- and 1.18-mm screens, and the bottom pan of the PSPS were 3.2, 37.5, 48.2 and 11.1%, respectively, and particle size distribution for the forage mixture was numerically similar across diets.

1.2. DM Intake, Milk Yield and Milk Composition, and Plasma Metabolites: Dry matter intake tended to be lower ($P = 0.10$) for cows fed the wheat-based TMR than cows on the barley-based

TMR. Cows fed barley-, corn- or oats-based TMR consumed 2.2, 2.0 and 1.2 kg/d of DM more, respectively, compared to those fed the wheat-based TMR (Table 2). Actual milk yield also tended to be lower ($P = 0.06$) in cows fed the wheat-based diet compared to those fed the barley-based TMR. On average, cows fed barley-, corn- and oats-based TMR produced 3.4, 2.1 and 1.6 kg/d more milk, respectively, compared to those fed the wheat-based TMR (Table 2). According to dietary NE_l estimates from the NRC (2001), the extra DM consumed by cows fed the barley-, corn- or oats-based TMR above that of cows fed the wheat-based TMR corresponds to an additional intake of between 1.9 and 3.5 Mcal/d of NE_l which would explain the higher milk yield. Assuming caloric values of 9.3, 5.9, and 4.0 kcal/g of milk fat, protein, and lactose, respectively (Arieli et al., 2001), this extra NE_l intake corresponds to an additional 5.5, 4.7, and 2.9 kg/d of milk (assuming similar milk contents of fat, protein, and lactose as indicated in Table 2) in cows fed barley-, corn-, and oats-based TMR, respectively. The observed differences in milk production among dietary treatments did not achieve the levels predicted from estimated energy intakes; however the pattern of difference appears to be similar to that predicted. Standardizing milk to 3.5% FCM yield accentuated the differences in yield between wheat-, and corn-based TMR ($P = 0.02$) and wheat-, and barley-based TMR ($P = 0.05$) (Table 2).

A preponderance of comparative studies conducted under North American conditions have investigated production responses in trials comparing fewer cereal grain types, most commonly corn and barley. Additionally, the few studies in the literature showed variable production responses. Tommervik and Waldern (1969) reported similar milk yields across dietary treatments when diets containing wheat, barley, oats, or corn were fed. Similarly, grazing cows supplemented with 3 kg/d of wheat, barley, oats or corn yielded similar amounts of milk (Jeffery et al., 1976). Moran (1986) reported higher FCM yields in cows fed oats-based diets compared to those fed wheat- or barley-based diets, although DM intakes were similar for all diets. Grings et al. (1992)

and Khorasani et al. (1994) did not observe any dietary effects on milk yield with diets containing either corn or barley as the principal source of starch. In contrast, others (McCarthy et al., 1989; Casper et al., 1999) reported stimulatory effects on milk yield in cows fed corn-based compared to barley-based diets. Among other things, responses of lactating cows to different cereal grains depend on the level of dietary inclusion, the basal ration, physical processing of the cereal grains, the composition of a given batch of cereal grain, and the level of dietary intake (Moran, 1986; Khorasani et al., 2001); therefore, direct comparisons among studies are often not possible.

In the current study, feeding the corn-based TMR resulted in higher fat content compared to feeding the barley-based ($P = 0.05$) or wheat-based ($P = 0.04$) TMR whilst fat yield was only higher ($P < 0.01$) in cows fed corn-, compared to wheat-based TMR diets (Table 2). In contrast, Tommervik and Waldern (1969) reported similar milk fat contents and yields in cows fed wheat, barley, oats or corn as the principal energy concentrates. Similarly, Moran et al. (1986) reported no differences in milk fat content in cows fed wheat, barley or oats; however, milk fat yield was higher in cows fed oats compared with those fed barley or wheat. Higher fat content in milk from cows fed corn compared to those fed barley diets have been reported previously (DePeters and Taylor, 1985; Weiss et al., 1989; Khorasani et al., 2001). Dietary differences on milk compositional quality are generally reflective of differences in patterns of ruminal fermentation (Moran, 1986) and in the site and extent of cereal grain digestion (Khorasani et al., 2001). Previous studies have reported milk fat depression with decreased ruminal acetate to propionate ratios (Griinari et al., 1998; Onetti et al., 2002); however, the acetate to propionate ratios in the present study did not differ across dietary treatments. Milk protein content was higher ($P = 0.01$) in cows fed corn-based TMR compared to those fed oats-based TMR while protein yield tended to be lower in cows fed wheat-based TMR compared to those fed barley-based TMR ($P = 0.05$) or corn-based TMR ($P = 0.10$). This was partly due to the tendency for higher milk yield in cows fed the barley-, and corn-based TMR compared to

cows fed the wheat-based TMR. Milk lactose content did not differ ($P = 0.10$) among dietary treatments (Table 2).

Plasma concentrations of glucose did not respond to dietary treatment (Table 2). Under most dietary conditions, intestinal absorption of glucose in dairy cows is limited due to the extensive ruminal fermentation of dietary starch; thus, plasma glucose largely arises from hepatic gluconeogenesis using ruminally-derived propionate as the principal precursor (Huntington, 1997). In the present study, ruminal propionate concentrations were not altered by dietary treatment, so this observation might partly explain the lack of dietary differences in plasma glucose. Plasma urea-N tended to be higher in cows fed the oats-based TMR compared to those fed the barley-, corn-, or wheat-based TMR (Table 2; $P = 0.10$). In dairy cows, PUN largely arises from ruminal catabolism of dietary protein, with the resultant ruminal NH_3-N that is not captured for microbial protein synthesis being absorbed into portal blood and converted to urea in the liver (NRC, 2001). Although numerous factors determine the efficiency of capture of ruminal NH_3-N for microbial growth, total starch and ruminally-degradable starch (**RDS**) intake appear to be the major factors (Theurer et al., 1999). In the present study, cows fed the oats-based TMR consumed 1.2 to 1.8 kg/d less starch compared to those fed the barley-, corn-, and wheat-based TMR. The lower starch intake in cows fed the oats-based diet could potentially limit the ability of ruminal microorganisms to utilize ruminal NH_3-N, thus resulting in higher rates of ureagenesis. However, it is noteworthy that dietary differences in ruminal concentrations of NH_3-N were absent. Others (Casper et al., 1999) found no effect of barley-, or corn-based diets on PUN.

1.3. Ruminal Fermentation Characteristics and Apparent Total Tract Diet Digestibility: Ruminal pH was unaffected by dietary treatment (Table 3). Cereal grains differ in their starch contents, and rates and extents of ruminal starch fermentation (Huntington, 1997), with oats and wheat exhibiting a faster and more extensive ruminal starch degradation compared to barley or corn. Therefore,

dietary differences in ruminal pH were expected and the reasons for a lack of effect on ruminal pH are unclear. Cows fed the oats-based TMR consumed 1.2 to 1.8 kg/d less starch compared to those fed the barley-, corn-, and wheat-based TMR, so it is plausible that the lack of dietary differences in ruminal pH could be attributable to the lower starch intakes in cows fed oats-based TMR. Additionally, it is possible that a more intensive sampling schedule during a 24-hour feeding cycle or the use of continuous ruminal pH measurements may have been able to give a definitive indication of changes in pH. Additionally, high NDF concentrations across all dietary treatments may have resulted in high rumen buffering. Dietary NDF concentration is inversely related to ruminal pH as higher dietary NDF promotes less ruminal acid production, and stimulates chewing and saliva production (NRC, 2001), which could have resulted in smaller, undetectable differences in ruminal pH across dietary treatments. In comparative studies with diets containing barley, wheat, or oats as the principal starch sources, ruminal pH was not affected by the choice of cereal grain (Moran, 1986), and this is similar to findings of the present study. Ruminal pH ranged from 5.8 to 6.9 and, as expected, declined with time post-feeding in a similar pattern across dietary treatments.

Ruminal NH_3-N concentration was unaffected by dietary treatment (Table 3). Moran (1986) fed dairy cows complete diets containing barley, wheat or oats as the principal starch sources and did not observe dietary effects on ruminal NH_3-N concentration. Across dietary treatments, ruminal NH_3-N concentrations ranged from 9 to 24 mg/dL and changes in ruminal NH_3-N concentrations with time post-feeding were similar across diets. Mean ruminal NH_3-N concentrations were >5 mg/dL at all sampling times post-feeding, which has been suggested to be adequate for maximum microbial protein synthesis (Satter and Slyter, 1974).

Individual concentrations for most ruminal VFA were not affected by dietary treatment but the concentration of valerate tended to be lower ($P = 0.07$) for cows fed oats- based TMR

compared to those fed wheat-based TMR (Table 3). Total VFA concentrations were also unaffected by dietary treatment (Table 3). Consequently, the acetate to propionate ratio was also not affected by dietary treatment. As the rate of ruminal starch degradation is different among cereal grains, it is reasonable to expect differences in ruminal VFA concentrations when diets containing different cereal grains are fed. In other comparative studies with corn and barley, differences in ruminal patterns of VFA were small or absent (DePeters and Taylor, 1985; Weiss et al., 1989). Since ruminal fermentation characteristics were measured just prior to feeding and at 2-hourly intervals for 6 h after morning feeding, a time x treatment interaction for ruminal pH, ruminal ammonia and VFA would be indicative of differences in fermentation patterns; however, there was no treatment x time interaction for any of the ruminal fermentation characteristics measured which indicates that fermentation patterns were essentially similar across diets (Table 3).

Total tract digestibility of DM, OM, and NDF were not affected by dietary source of carbohydrate (Table 4). Total tract ADF digestibility tended to be lower ($P = 0.10$) in cows fed the wheat-based TMR compared with those fed the corn-based TMR (Table 4). Compared to cows fed the oats-based TMR, apparent total tract starch digestibility was lower in cows fed the corn-based ($P = 0.01$), or wheat-based ($P < 0.01$) TMR. Apparent total tract starch digestibility also tended to be lower ($P = 0.08$) in cows fed the barley based TMR than in those fed the oats-based TMR (Table 4). Across dietary treatments, apparent total tract starch digestibility was >90%. In dairy cows, the major site of cereal grain starch digestion is the rumen and, with oats exhibiting a faster and more extensive ruminal starch degradation compared to wheat, barley and corn (Huntington, 1997), it was expected that total tract starch digestibility would be higher in cows fed the oats-based TMR. Moran (1986) also reported a higher total tract starch digestibility in dairy cows fed oats compared to those fed wheat or barley.

Compared to cows fed the oats-based TMR, apparent total tract CP digestibility was lower in cows fed the corn-based ($P = 0.02$), and wheat-based ($P = 0.01$) TMR (Table 4). This response might be related to the relative extents of ruminal starch degradation of the cereal grains. Higher levels of undigested starch reaching the hindgut in cows fed the corn- and wheat-based diets compared to those fed the oats-based diet might have promoted more bacterial protein synthesis in the hindgut (Orskov et al., 1970). Because there is no mechanism for hindgut enzymatic digestion of the resultant bacterial protein, it is voided in the feces, thus reducing the total tract CP digestibility (Orskov et al., 1970). In addition, differences in apparent total tract CP digestibility may be due to differences in the digestibility of the protein of the cereal grains (Herrera-Saldana et al., 1990; McAllister et al., 1993).

1.4. Nitrogen Balance and Microbial N Flow: Nitrogen intake was similar across diets, in part because DMI (i.e., for cows used in the metabolism trial; see Table 4) was not affected by treatment and also because the diets were formulated to be isonitrogenous (Table 5). However, as a proportion of N intake, fecal N excretion was highest in cows fed the wheat- and corn-based diets, intermediate in those fed the barley-based diet, and lowest for those fed the oats-based diet (Table 5). Urinary N excretion, as a proportion of N, intake tended to be lower ($P = 0.09$) in cows fed corn-based diets compared with those fed wheat-based diets. As a proportion of urinary N, urea-N was higher ($P < 0.01$) in cows fed corn- and oats-based diets. Nitrogen that was used for productive purposes (N secreted in milk plus N apparently retained by the cow) tended to be lower ($P = 0.06$) in cows fed the wheat- based diet compared to cows fed barley-, corn- or oats-based diets, reflecting the higher total N excretion (expressed as a % of N intake) in cows fed the wheat-based diet (Table 5). Additionally, the wheat-based diet contained less canola meal and soybean meal compared with the other diets (Table 1), and this could potentially limit metabolizable protein flow to the small intestine in cows fed the wheat-based diet. When urinary N excretion was expressed as

a proportion of N intake (Table 5), cereal grains were ranked as wheat > oats > barley > corn, which is the reverse ranking in terms of predicted ruminal starch digestibility (Huntington, 1997).

Total purine excretion was higher ($P = 0.04$) in cows fed the barley-based diets compared to those fed the oats-based diets, and intermediate in cows fed the corn-, and wheat-based TMR (Table 6). Consequently, the calculated intestinal flow of microbial N was also higher ($P = 0.04$) in cows fed the barley-based TMR compared with those fed the oats-based TMR (Table 6). Based on DMI and dietary starch contents, cows fed the oats-based TMR consumed 1.2 to 1.8 kg/d less starch compared to those fed the barley-, corn-, and wheat-based TMR. A lower total starch intake in cows fed the oats-based TMR could partly explain the lower total PD excretion and, consequently, the lower intestinal flow of microbial N when compared to cows fed the barley-based TMR. Data summarized by Theurer et al. (1999) showed that a decrease in total starch or RDS intake was associated with a decrease in microbial N flow in dairy cows. Considering that there were only numerical differences in DMI, the wheat-based diet was expected to result in improved microbial N flow to the duodenum due to a higher RDS intake (Firkins et al., 2001), when compared to the barley- or corn-based diets. However, dietary RDP content in the wheat-based TMR may have differed from that of the other diets due to a lower content of canola meal and soybean meal. Lower levels of these ingredients in the wheat-based TMR were necessary in order to achieve isonitrogenous experimental diets with all 4 cereal grains. The effect of RDS in the diet has not always yielded consistent results in previous studies in the literature. For example, a review of the literature by Cabrita et al. (2006) shows that more RDS in the diet increased microbial N supply in 2 studies and had no effect in 5 studies. In the present study, inclusion of the less degradable starch sources (barley and corn, compared to wheat) in the diet increased microbial N supply.

Table 1. Ingredient composition and chemical analysis of experimental TMR fed to lactating dairy cows

Item	Source of carbohydrate in the diet			
	Barley	Corn	Wheat	Oats
TMR ingredients, % of diet DM				
Barley silage	29.8	30.1	32.1	30.0
Alfalfa hay	18.1	18.3	19.5	18.2
Barley	31.1	-	-	-
Corn	-	28.7	-	-
Wheat	-	-	32.8	-
Oats	-	-	-	30.5
Canola seed	5.4	4.0	5.8	3.5
Canola meal	3.8	5.5	1.9	5.5
Soybean meal	5.7	7.3	1.4	6.2
Corn gluten meal	1.0	1.0	1.1	1.0
Wheat distillers dried grains	2.0	2.0	2.1	2.0
Canola oil	0.41	0.42	0.44	0.42
Molasses	0.42	0.42	0.45	0.42
Mineral and vitamin premix[1]	1.7	1.7	1.8	1.7
Salt	0.34	0.35	0.37	0.35
Dynamate[2]	0.15	0.16	0.17	0.16
Chemical composition				
DM, %	54.5	54.3	54.3	55.1
CP, % of DM	17.6	17.2	17.4	17.3
ADF, % of DM	26.8	25.9	26.5	27.3
NDF, % of DM	32.7	32.9	33.0	35.7
Starch, % of DM	19.2	21.8	22.4	15.2
Ether extract, % of DM	5.3	5.4	5.4	5.8
NE_l, Mcal/kg of DM[3]	1.6	1.6	1.6	1.6

[1]Contained (kg^{-1} premix; DM basis): 330,000 IU of vitamin A, 60,000 IU of vitamin D, 1000 IU of vitamin E, 16% Ca, 8.5% P, 6.3% Na, 4.5% Mg, 2,100 mg Zn, 1,500 mg Mn, 535 mg Cu, 12 mg Se, 45 mg I.

[2]Dynamate (Eastern Minerals Inc., Henderson, NC) contained 18% K, 11% Mg, and 22% S.

[3]Calculated from NRC (2001).

Table 2. Dry matter intake, milk yield and milk composition, and plasma metabolites of dairy cows fed diets containing barley, corn, wheat and oats as the main source of carbohydrate[1]

	Source of carbohydrate in the diet					
Item	Barley	Corn	Wheat	Oats	SEM	*P* value[2]
DMI, kg/d	26.2	26.0	24.0	25.2	0.59	0.07
Milk yield, kg/d	40.2	38.9	36.8	38.4	0.80	0.06
3.5% FCM[3], kg/d	37.9^{a}	38.4^{a}	34.8^{b}	37.0^{ab}	0.72	0.02
Fat, %	3.20^{b}	3.45^{a}	3.20^{b}	3.34^{ab}	0.05	0.02
Fat yield, kg/d	1.26^{ab}	1.33^{a}	1.16^{b}	1.26^{ab}	0.03	<0.01
Protein, %	3.00^{ab}	3.07^{a}	3.00^{ab}	2.96^{b}	0.03	0.02
Protein yield, kg/d	1.20^{a}	1.18^{ab}	1.10^{b}	1.12^{ab}	0.02	0.02
Lactose, %	4.33	4.39	4.35	4.34	0.02	0.10
Plasma glucose, mg/dL	45.4	46.9	47.5	45.7	0.78	0.25
Plasma urea-N, mg/dL	18.1	16.9	17.5	19.0	0.57	0.10

[1]Data was obtained from all 8 cows used in the 2 Latin squares.

[2]*P* values indicate overall diet effects.

[ab]Means within a row with different superscripts differ ($P < 0.05$). Means were separated using Bonferoni's procedure (SAS, 2004).

[3]Calculated as (0.434 x kg of milk) + (16.216 x kg of milk fat).

Table 3. Ruminal fermentation characteristics of dairy cows fed diets containing barley, corn, wheat and oats as the main source of carbohydrate[1]

Item	Source of carbohydrate in the diet				SEM	*P* values		
	Barley	Corn	Wheat	Oats		Cereal	Time	Cereal x Time
Ruminal pH	6.26	6.18	6.11	6.20	0.11	0.84	<0.01	0.11
Ruminal NH_3-N, mg/dL	15.6	16.0	15.6	14.5	1.37	0.86	<0.01	0.66
VFA concentrations, m*M*								
Acetate	68.6	71.4	72.6	67.9	3.04	0.67	<0.01	0.11
Propionate	22.1	22.5	27.6	22.4	2.74	0.45	<0.01	0.28
Butyrate	13.8	14.8	13.2	13.2	1.13	0.72	<0.01	0.92
Isobutyrate	1.22	1.29	1.35	1.11	0.08	0.15	<0.01	0.89
Valerate	1.92	1.85	2.44	1.71	0.19	0.05	<0.01	0.96
Isovalerate	1.98	1.97	2.01	1.74	0.23	0.84	<0.01	0.66
Total VFA	102.6	111.0	124.2	99.6	6.46	0.59	<0.01	0.24
Acetate:Propionate ratio	3.21	3.24	2.83	3.15	0.28	0.58	<0.01	0.85

[1]Values are means across sampling times of 0, 2, 4, and 6 h after a.m. feeding.

Table 4. Total tract nutrient digestibility of dairy cows fed diets containing barley, corn, wheat and oats as the main source of carbohydrate[1]

	Source of carbohydrate in the diet					
Item	Barley	Corn	Wheat	Oats	SEM	*P* value[2]
DMI, kg/d	25.8	26.3	24.0	24.8	1.51	0.72
Digestibility, %						
DM	63.7	63.1	59.5	62.1	1.39	0.22
OM	65.7	64.6	61.2	63.9	1.30	0.16
CP	66.3^{ab}	63.2^{b}	62.9^{b}	70.1^{a}	1.21	<0.01
ADF	45.2	49.2	37.7	39.3	2.72	0.05
NDF	41 1	43.4	30.2	38.5	3.55	0.11
Starch	92.6^{ab}	91.3^{b}	90.9^{b}	95.8^{a}	0.72	<0.01

[1]Measurements were done only in the 4 ruminally-cannulated cows.

[2]*P* values indicate overall diet effects.

[ab]Means within a row with different superscripts differ ($P < 0.05$). Means were separated using Bonferoni's procedure (SAS, 2004).

Table 5. Nitrogen balance in dairy cows fed diets containing barley, corn, wheat and oats as the main source of carbohydrate

Item	Source of carbohydrate in the diet				SEM	*P* value[1]
	Barley	Corn	Wheat	Oats		
N intake, g/d	727	723	669	686	38.4	0.35
Fecal N excretion						
g/d	246	266	251	207	14.8	0.09
% of N intake	33.9^{ab}	36.8^{a}	37.4^{a}	30.3^{b}	1.00	<0.01
Urinary N excretion						
g/d	267	236	255	265	15.0	0.47
% of N intake	36.8	32.8	40.0	38.2	1.75	0.10
% of total N excretion	52.0^{ab}	46.8^{b}	50.5^{ab}	56.2^{a}	1.27	0.01
Urea-N, g/d	219	223	210	238	14.7	0.56
Urea-N, % of urinary N	82^{b}	94^{a}	82^{b}	90^{ab}	2.25	<0.01
Total N excretion, g/d	513	501	506	472	27.8	0.74
N retention, g/d	35	43	-5	48	16.2	0.10
Milk N, g/d	179	178	168	166	11.0	0.30
Productive N[2], g/d	214	221	163	214	22.0	0.06

[1]*P* values indicate overall diet effects.

[ab]Means within a row with different superscripts differ ($P < 0.05$). Means were separated using Bonferoni's procedure (SAS, 2004).

[2]Calculated as N secreted in milk plus N apparently retained by the cow.

Table 6. Urine output, urinary purine derivative excretion, and microbial N supply in dairy cows fed diets containing barley, corn, wheat and oats as the main source of carbohydrate

Item	Source of carbohydrate in the diet				SEM	*P* value[1]
	Barley	Corn	Wheat	Oats		
Urine output, kg/d	29.0[ab]	30.5[a]	27.6[ab]	26.4[b]	1.93	0.03
Allantoin, mmol/d	378	369	344	325	10.3	0.04
Uric acid, mmol/d	57	58	53	53	6.21	0.80
Total purine derivatives, mmol/d	436[a]	427[ab]	397[ab]	379[b]	14.2	0.02
Microbial N supply[2], g/d	324[a]	316[ab]	291[ab]	275[b]	8.60	0.02

[1]*P* values indicate overall diet effects.

[ab]Means within a row with different superscripts differ ($P < 0.05$). Means were separated using Bonferoni's procedure (SAS, 2004).

[2]Calculations based on equation from Chen and Gomes (1992).

2. EXPERIMENT 2:

2.1. Diet Characteristics: The ingredient composition and chemical analysis of experimental TMR is presented in Table 7. The experimental diets were formulated to meet requirements for dairy cows that were 650 kg BW, producing 32 kg/d of milk with 3.6% fat (NRC, 2001). Diets were formulated to be isonitrogenous and isolipidic, and chemical analysis indicates that this was achieved (Table 7). Mean total dietary fat was 5.3%, and this falls within the desired range of <6% total dietary fat. Dietary fat levels exceeding 6 to 7% reduce fiber digestion and, consequently, lower DM intake in dairy cows (NRC, 2001), hence it was desired to maintain total dietary fat below 6% of DM. Whole canola seed and whole flaxseed were chosen to be used as supplemental fat sources in this experiment for 2 major reasons. Firstly, they are both readily available and are commonly used in dairy cow diets in western Canada and the northern USA. Secondly, canola seed and flaxseed differ in their unsaturated fatty acid contents. The FA composition (g per 100 g of FA) of canola seed was: $C_{16:0}$, 5.44; $C_{16:1}$, 0.23; $C_{18:0}$, 1.77; $C_{18:1}$, 57.1; $C_{18:2}$, 22.9; and $C_{18:3}$, 11.7. The fatty acid composition (g/100 g of FA) of flaxseed was: $C_{12:0}$, 0.04; $C_{14:0}$, 0.16; $C_{14:1}$, 0.03; $C_{16:0}$, 6.28; $C_{16:1}$, 0.15; $C_{18:0}$, 3.32; $C_{18:1}$, 16.7; $C_{18:2}$, 15.2; and $C_{18:3}$, 55.3. Therefore, canola seed is high in oleic ($C_{18:1}$) and linoleic acids ($C_{18:2}$), whereas flaxseed is high in linolenic acid ($C_{18:3}$). In addition, these oilseeds differed in their iodine values, (calculated from individual fatty acid composition; AOCS, 1989), with mean values of 112 to 115 and 190 for canola seed and flaxseed, respectively. Because of these differences in the degree of unsaturation of these oilseeds, we expected that their impacts on ruminal microbes and, consequently, on ruminal fermentation patterns would be different.

Dietary ruminally-fermentable carbohydrate was altered via barley grain processing (i.e., dry-rolling versus pelleting). Pelleting was expected to decrease particle size, thus shifting the site of carbohydrate digestion from post-ruminal sites to the rumen, which, consequently, would

increase ruminal energy availability. Previous in situ studies in our laboratory clearly indicated a higher soluble starch fraction, a higher degradation rate of the degradable starch fraction, and a higher effective starch degradability of pelleted barley when compared to dry-rolled barley (D. Kiran and T. Mutsvangwa, unpublished data). In the present study, a more acidic ruminal environment in cows fed pelleted barley compared to those fed dry-rolled barley is consistent with a shift in site of starch digestion. Also, barley grain was used because it is the principal cereal grain that is included in dairy cow diets in western Canada, and it is commonly fed either dry-rolled or pelleted.

2.2. Patterns of Ruminal Fermentation: Ruminal pH was 0.22 to 0.40 pH units greater ($P = 0.05$) in cows fed dry-rolled barley compared to those fed pelleted barley (Table 8). This was not unexpected as more extensive processing of barley would result in a more rapid and extensive ruminal carbohydrate fermentation (Huntington, 1997), thus increasing the risk of ruminal acidosis. Similarly, Yang et al. (2000) reported a lower ruminal pH in cows fed medium- or flat-rolled barley compared to those fed coarsely-rolled barley. Individual and total concentrations of VFA were greater ($P < 0.05$) in cows fed dry-rolled barley compared to those fed pelleted barley; consequently, the acetate:propionate ratio was higher ($P < 0.001$) in cows fed dry-rolled barley compared to those fed pelleted barley (Table 8). As the rate of ruminal starch degradation is expected to differ with method of grain processing, it is reasonable to expect differences in ruminal VFA patterns, particularly acetate and propionate, when barley grain is fed either dry-rolled or pelleted. There were no time x method of barley processing interactions for the major ruminal VFA; however, there was a time x method of barley processing interaction for valerate ($P = 0.01$) because ruminal concentrations of valerate were similar at feeding, but were higher at all other sampling times in cows fed dry-rolled barley compared to those fed pelleted barley (data not shown). In addition, there was a time x method of barley processing interaction for

isovalerate ($P < 0.001$) because ruminal concentrations of isovalerate were higher at all sampling times during the first 20 h after the first feeding in cows fed dry-rolled barley compared to those fed pelleted barley, but were similar thereafter (data not shown). There were no effects of source of supplemental fat on ruminal VFA (Table 8); however, there was a time x source of supplemental fat interaction ($P < 0.01$) for butyrate because ruminal butyrate concentrations were higher at 8 h after the first feeding, but tended ($P < 0.1$) to be lower at 16 and 20 h after the first feeding, in cows fed whole canola seed compared to those fed whole flaxseed (data not shown). In addition, there was a time x source of supplemental fat interaction ($P = 0.04$) for isobutyrate as ruminal isobutyrate concentrations tended ($P < 0.10$) to be higher at 12 and 20 h after the first feeding, but were higher ($P = 0.01$) at 16 h after the first feeding in cows fed whole canola seed compared to those fed whole flaxseed (data not shown).

Across dietary treatments, ruminal NH_3-N concentrations ranged from 13.9 to 19.9 mg/dL and mean ruminal NH_3-N concentrations at all sampling times post-feeding were >5 mg/dL (data not shown), which has been suggested to be optimum for maximum microbial protein synthesis (Satter and Slyter, 1974). Ruminal NH_3-N concentration was greater ($P = 0.02$) in cows fed dry-rolled barley compared to those fed pelleted barley (Table 8). The lower ruminal NH_3-N concentration in cows fed pelleted barley likely reflects reduced microbial proteolytic activity as a result of a more acidic ruminal environment (Van Soest, 1994). Conversely, a lower ruminal NH_3-N concentration may also be as a result of a higher level of utilization of NH_3-N as a result of more readily available carbohydrate in pelleted barley diets (Hristov et al., 2001). In agreement with our observations, Yang et al. (2000; 2001) also reported a lower ruminal NH_3-N concentration in cows fed more extensively-processed barley compared to those fed coarsely-rolled barley. There was a time x method of barley processing interaction for ruminal NH_3-N concentration ($P < 0.001$) because ruminal NH_3-N concentrations were higher in cows fed dry-

rolled barley compared to those fed pelleted barley for the first 8 h after the first feeding, but ruminal NH_3-N concentrations were similar thereafter (data not shown).

2.3. Dry Matter Intake and Total Tract Digestibilities: Dry matter intake (DMI) was affected ($P = 0.04$) by method of barley grain processing, with cows fed dry-rolled barley consuming 1.2 to 3.3 kg/d more DMI compared to those fed pelleted barley (Table 9). This depression in DMI with more extensive barley processing is likely mediated via increased acidity in the rumens of cows fed pelleted barley. The lower DMI in cows consuming pelleted barley compared to those fed dry-rolled barley diets is in agreement with results reported by Yang et al. (2000), who observed a quadratic response in DMI of dairy cows fed barley grain processed to varying degrees, ranging from coarsely-rolled to flat-rolled. In feedlot cattle, Hironaka et al. (1992) observed lower DMI and a higher incidence of digestive disturbances when thinly-rolled or medium-rolled barley diets were fed compared to coarsely-rolled or whole barley diets. In contrast, Yang et al. (2001) reported higher DMI in cows fed flatly-rolled barley compared to those fed coarsely-rolled barley; however, the decrease in ruminal pH (-0.13 pH units) observed with more extensive barley grain processing in that study was not as severe as that observed in the present study (-0.31 pH units), and this could explain the discrepancy in results. Source of dietary supplemental fat did not affect DMI (Table 9). Mean DMI was 22 kg/d, or approximately 3.4% of mean BW, and this falls within the expected range for dairy cows producing 32 kg/d of milk (NRC, 2001). Therefore it is unlikely that feeding supplemental fat decreased DMI. These results are in agreement with those of Ward et al. (2002) in which DMI was similar in cows fed barley-based diets that contained either canola or flax as a supplemental fat source.

Total tract digestibilities of DM, crude fat, ADF, NDF and OM were unaffected ($P > 0.05$) by method of barley processing or source of oilseed (Table 9); however, total tract starch digestibility was higher ($P < 0.0001$) in cows fed pelleted barley compared to those fed dry-rolled

barley (Table 9). In contrast, Yang et al. (2001) reported higher DM and OM digestibilities in cows fed flatly-rolled barley compared to those fed coarsely-rolled barley; however, in agreement with our observations, ADF and NDF digestibilities were not altered. Feeding dry-rolled barley may have reduced the rate of starch fermentability in the rumen while feeding pelleted barley led to a more rapid and complete ruminal starch degradation and, hence, higher starch digestibilities. The lack of effect of barley grain processing on ADF and NDF digestion is somewhat surprising because pelleting barley increased ruminal acidity when compared to dry-rolling. This is possibly due to a higher hindgut fermentation of ADF and NDF in cows fed dry-rolled barley compared to those fed pelleted barley, thus compensating for any depression in ruminal fiber digestion that might have occurred. Across dietary treatments, our estimates of total tract digestibilities of ADF and NDF are similar to previous observations in cows fed similar diets (T. Mutsvangwa, unpublished data); however, it is noteworthy that our estimates of ADF and NDF digestibilities are numerically lower than has been previously observed in cows fed diets with similar ingredient compositions (Yang et al., 2000). Lower ADF and NDF digestibilities observed in the present study might be attributed to depressed ruminal pH. In a previous study (Yang et al., 2000) reporting higher ADF and NDF digestibilities, mean ruminal pH was 0.17 to 0.43 pH units higher when compared to mean ruminal pH values observed in the present study. Across all diets, mean ruminal pH ranged from 5.73 to 6.11 (mean of 5.91), which is lower than the ruminal pH of 6.2 which has been suggested as the minimum ruminal pH for optimum fiber digestion (Van Soest, 1994). Previously, in vitro studies indicated that populations of the principal fiber-digesting bacteria such as *Fibrobacter* spp. and *Ruminococcus albus* decline rapidly when pH falls below 6.0 (Russell and Wilson, 1996). In addition, total dietary fat in the present study was high (>5%; DM basis) and composed mainly of unsaturated fatty acids. In general, supplemental fat sources that are high in unsaturated fatty acids can have inhibitory effects on ruminal fiber digestion

(Schauff et al., 1992; Pantoja et al., 1994), thus partially explaining the lower fiber digestibilities observed in the present study when compared to another study (Yang et al., 2000) in which total dietary fat contents were lower.

2.4. Milk Yield and Milk Composition: Actual and energy-corrected milk **(ECM)** were not affected by method of barley grain processing or source of supplemental fat (Table 10). These findings are similar to those by Ward et al. (2002) in which inclusion of flax or canola as supplemental fat source in barley-based diets to attain a dietary fat content of 6% (DM basis) did not affect milk yield. Milk fat content ($P < 0.0001$) and milk fat yield ($P < 0.0001$) were higher in cows fed dry-rolled barley than in cows fed pelleted barley (Table 10). Milk fat contents were 3.47% and 2.67%, and milk fat yields were 1.13 and 0.76 kg/d for cows fed dry-rolled barley and pelleted barley, respectively. Thus, milk fat yield tended ($P = 0.09$) to be lower due to the milk fat depression observed with pelleted barley, and these changes mirrored the numerical changes in milk yield. The milk fat depression observed in cows fed pelleted barley is likely attributed to ruminal fermentation changes, resulting in depressed ruminal pH and associated changes in ruminal biohydrogenation pathways. Previously, in vitro studies indicated that depressed pH altered biohydrogenation pathways of unsaturated fatty acids, such that there was an accumulation of $C_{18:1}$ *trans*-10 and conjugated linoleic acid (CLA) isomers (Van Nevel and Demeyer, 1996; Qui et al., 2004). These unsaturated fatty acids are potent inhibitors of de novo synthesis of short-chain fatty acids in the mammary gland (Bauman and Griinari, 2001). In the present study, post-ruminal flow of CLA isomers and $C_{18:1}$ *trans*-10, or milk fatty acid composition, were not measured. However, the milk fat depression in cows fed pelleted barley suggests that post-ruminal flow of these biohydrogenation intermediates may have been higher than in cows fed dry-rolled barley. Additionally, a lower ruminal acetate: propionate ratio in cows fed pelleted barley compared to those fed dry-rolled barley may be a possible cause for the

observed milk fat depression. Others have reported milk fat depression when ruminal fermentation was altered sufficiently to decrease acetate: propionate ratios (Griinari et al. 1998; Onetti et al. 2002). Milk protein content was higher ($P = 0.005$) in cows fed dry-rolled barley compared to those fed pelleted barley (Table 10). Additionally, feeding whole flaxseed as supplemental fat resulted in higher ($P = 0.01$) milk protein content compared to feeding whole canola (Table 10). Previous studies in which dietary barley grain was processed more extensively (Yang et al., 2001), or whole canola and flaxseed were added as supplemental fat sources (Ward et al., 2002) have also reported changes in milk protein content and milk protein yield.

2.5. Nitrogen Balance: Cows fed dry-rolled barley consumed 1.2 to 3.3 kg/d more DM compared to those fed pelleted barley, which resulted in cows fed dry-rolled barley consuming 40 to 113 g/d more N compared to those fed pelleted barley ($P = 0.02$; Table 11). However, fecal N excretion was higher ($P = 0.002$) in cows fed dry-rolled barley compared to those fed pelleted barley (Table 11). As a result, cows fed dry-rolled barley had a lower ($P = 0.05$) apparent N digestibility compared to those fed pelleted barley (Table 11). Lower apparent N digestibilities in cows fed dry-rolled barley compared to those fed pelleted barley suggest that a larger fraction of dietary starch was able to bypass the rumen and was digested in the lower GIT. Shifting starch digestion to the lower GIT promotes hindgut fermentation and leads to more bacterial protein synthesis in the hindgut (Orskov et al., 1970); however, there are no mechanisms for digestion and absorption of the resultant bacterial protein, which is subsequently voided in the feces. Nitrogen use (i.e., N secreted in milk, N retained by the animal, or excreted in urine N) were not affected ($P > 0.05$) by dietary treatment (Table 11). In the present study, we observed a rather large variability in urinary and fecal N excretion, so these data on N balance should be interpreted somewhat cautiously. Spanghero and Kowalski (1997) conducted a meta-analysis of 35 trials that were conducted with dairy cows and found that the mean and median N balance were 39 and 24

g/d, respectively. In the present study, mean N balance ranged from 21.5 to 43.7 g/d, which encompasses the mean N balance reported by Spanghero and Kowalski (1997). Typically, N balance is calculated as N intake-(milk N + fecal N + urine N); therefore, any errors that occur in the measurement of any of the 4 variables that are included in this calculation will be reflected in the N balance data. In addition, N balance data from studies with dairy cows have often been shown to be inherently flawed because the methodologies used often result in unaccountable N losses (Spanghero and Kowalski, 1997). In the present study, it is also possible that urinary and fecal N were underestimated due to possible gaseous N losses particularly during sample collection and processing (e.g., oven drying of fecal samples might have resulted in the loss of volatile N-containing compounds); however, the magnitude of these losses, if any, is unknown. Plasma urea-N concentration was not affected ($P > 0.05$) by dietary treatment (Table 11). In dairy cows, PUN largely arises from ruminal catabolism of dietary protein, with the resultant ruminal NH_3-N that is not captured for microbial protein synthesis being absorbed into portal blood and converted to urea in the liver (NRC, 2001).

2.6. Urea-N Kinetics and Microbial NAN Supply: The primary objective of the present study was to determine how interactions between method of barley grain processing and source of supplemental fat alter urea-N transfer to the GIT and the utilization of this recycled urea-N in dairy cows as measured by the intra-jugular [$^{15}N^{15}N$]-urea infusion protocol. Urea synthesis (i.e., urea-N entry rate; UER) was higher ($P = 0.02$) in dairy cows fed dry-rolled barley compared to those fed pelleted barley (Table 12). Higher UER in cows fed dry-rolled barley is not surprising; an extensive evaluation of experimental data on trans-hepatic venous-arterial (V-A) urea-N fluxes in beef and dairy cattle at variable N intakes and productive states indicated a strong, positive correlation ($r^2 = 0.96$) between N intake and hepatic output of urea-N (Huntington and Archibeque, 1999). In the present study, cows fed dry-rolled barley consumed more N compared

to those fed pelleted barley. Recently, higher levels of UER with increasing N intakes have been reported in lambs (Marini et al., 2004), Holstein heifers (Marini and Amburgh, 2003) and beef steers (Archibeque et al., 2001). There was a tendency (interaction; $P = 0.08$) for the difference in UER between cows fed dry-rolled barley compared to those fed pelleted barley to be greater with flax (178.9 g N/d) than canola (36.8 g N/d), likely because the difference in N intake between cows fed dry-rolled barley compared to those fed pelleted barley was greater with flax (113.7 g N/d) than canola (39.8 g N/d). Across dietary treatments, UER ranged from 0.72 to 1.06 of digestible N intake. In an elegant review of the literature, Lapierre and Lobley (2001) calculated UER:digestible N intake ratios in lactating cows at various levels of production and fed a wide variety of diets, and the calculated ratios ranged from 0.43 to 1.23 (mean of 0.88), a range which encompasses the ratios observed in the present study. Clearly, these ratios indicate the magnitude of the transit of N into the urea pool and the perpetual reliance of ruminants on urea-N recycling to the GIT in order to maintain a positive N balance.

The quantity of urea-N synthesized that was transferred to the GIT (i.e., GER) tended to be higher ($P = 0.07$) in cows fed dry-rolled barley compared to those fed pelleted barley (Table 12). In ruminants, the ability to transfer significant amounts of urea-N to the GIT, particularly to the rumen where it can be used for microbial protein synthesis, is an important mechanism to conserve N (Huntington, 1989). Increasing ruminal energy supply, either by increasing the amounts of readily-fermentable starch fed (Kennedy and Milligan, 1980; Huntington, 1989; Rémond et al., 1996) or by increasing the proportion of dietary starch fermented in the rumen via cereal grain processing (Alio et al., 2000; Theurer et al., 2002) increases urea-N transfer to the rumen. Based on these previous studies, we expected that decreasing barley particle size through pelleting compared to dry-rolling in our study would increase ruminal starch digestion and, consequently, increase the quantitative transfer of urea-N to the rumen. However, our

observations contradict these expectations. A possible explanation for this is that ruminal energy supply was not quantitatively higher in cows fed pelleted barley compared to those fed dry-rolled barley, primarily due to higher feed intake in cows fed dry-rolled barley (Table 9). The magnitude of urea-N transfer across the ruminal wall appears to be regulated by many intra-ruminal factors, including ruminal concentrations of VFA (particularly butyrate) and NH_3-N (Rémond et al., 1996). Increasing ruminal butyrate concentration promotes higher rates of urea-N transfer to the rumen (Engelhardt et al., 1978; Rémond et al., 1993). In the present study, cows fed dry-rolled barley exhibited a higher ruminal butyrate concentration compared to those fed pelleted barley, possibly accounting for the observed differences in GER. In addition, feeding pelleted barley increased ruminal acidity, which, in turn, might have decreased bacterial urease activity in the rumen. Because bacterial urease activity facilitates the trans-epithelial movement of urea-N by maintaining a concentration gradient that is favorable to diffusion (Rémond et al., 1996), depressed bacterial urease activity under the acidotic conditions imposed in cows fed pelleted barley might have impaired urea-N transfer. Previous studies reporting beneficial effects of increased ruminal energy availability on urea-N transfer to the rumen did not report associated changes, if any, in ruminal pH, so direct comparisons with the present study are not possible. When expressed as a proportion of UER, urea-N transfer to the GIT (i.e, GER:UER) was not changed ($P = 0.94$) by method of barley processing, and it ranged from 0.580 to 0.648 (Table 12). These values are similar to those observed by Alio et al. (2000) (0.50 to 0.67), and Theurer et al. (2002) (0.54 to 0.69) using V-A techniques in beef cattle fed cereal grains processed to varying degrees.

Despite a tendency for GER to be higher in cows fed dry-rolled barley compared to those fed pelleted barley, the proportion that was used in the GIT for anabolic purposes, both in absolute amounts (UUA) and as a proportion of GER (i.e., fractional transfer of GER to UUA),

were unaffected by dietary treatment (Table 12). Consequently, urea-N that was recycled to the ornithine cycle (i.e., ROC) was higher ($P = 0.03$) in dairy cows fed dry-rolled barley than in cows fed pelleted barley. Urea-N that is recycled to the rumen can potentially be utilized by ruminal microorganisms to increase microbial protein synthesis and, subsequently, total metabolizable protein flow to the small intestine. Other studies investigating the effects of increased ruminal starch digestion on N metabolism have reported increased urea-N recycling to the rumen, with concomitant increases in microbial protein flow to the small intestine (Al-Dehneh et al., 1997) or net absorption of α-amino N across the GIT (Alio et al., 2000). In the present study, only 0.161 to 0.206 of the GER was utilized for anabolic purposes (Table 12), and the lack of significant dietary effects on how much GER is directed towards anabolic purposes is consistent with similar microbial NAN flows as estimated using urinary PD excretion (Table 13). This lack of effect of grain processing on UUA suggests that energy supply did not limit utilization of the extra N provided via enhanced urea-N recycling to the GIT, probably because of the high levels of concentrate fed. It is also plausible that ruminal energy supply was quantitatively similar in cows fed either dry-rolled or pelleted barley, primarily due to differences in feed intake. In addition, some ruminal bacterial species that ferment non-structural carbohydrates have been demonstrated to have an absolute requirement for preformed peptides and amino acids (Oh et al., 1999), thus any additional ruminal N supply in the form of recycled urea-N could have precluded any further incorporation of N into microbial protein. In addition, the amount of GER that may be used for anabolic purposes will also depend on the proportion that actually enters the rumen since urea appears to enter all parts of the GIT (see Lapierre and Lobley, 2001). In the present study, a significant proportion of the GER, ranging from 0.761 to 0.804, was reabsorbed into portal blood as NH_3-N and returned to the urea cycle (GER to ROC; Table 12). Because of the high N intakes associated with lactating cows, a limit of N utilization for anabolic purposes in the GIT may

already have been reached (Lobley et al., 2000), thereby limiting anabolic use of any extra N supplied via recycling. Urea-N transfer to urine (i.e., UUE) was higher ($P = 0.05$) in cows fed dry-rolled barley compared to those fed pelleted barley (Table 12). This is likely attributable to the higher rates of endogenous urea-N production (i.e., UER) that was observed in cows fed dry-rolled barley compared to those fed pelleted barley. In other studies, higher UER has been associated with increased UUE (Marini and Amburgh, 2003; Marini et al., 2004; Lobley et al., 2000). Urea-N transfer to feces was unaffected by method of barley grain processing (Table 12). Fractional urea-N transfers of the GER to feces ranged from 0.033 to 0.037 across diets, and this represented the smallest proportion of GER (Table 12).

Source of supplemental fat in the diet did not alter urea N kinetics, either expressed as absolute amounts or as proportions of UER or GER (Table 12). We had hypothesized that as the degree of unsaturation of supplemental fat increased by substituting flaxseed for canola, then depressed activity of ruminal microbes, particularly ruminal protozoa, would reduce ruminal NH_3-N concentrations and, as a consequence, enhance urea-N transfer from the blood into the rumen. In previous studies reporting alterations in ruminal fermentation (Jenkins, 1993), bacterial N flow to the duodenum (Pantoja et al., 1994), and the efficiency of ruminal bacterial protein synthesis (Pantoja et al., 1994; Oldick and Firkins, 2000) as the degree of unsaturation of fat supplements increased, supplemental fat sources that differed markedly in their degree of unsaturation (tallow vs partially-hydrogenated vs animal-vegetable fat, with IV ranging from 10 to 110) were used. In those studies, alterations in ruminal fermentation characteristics as a result of changing supplemental fat source were usually observed, which was not the case in the present study. The absence of any effects of source of supplemental fat on urea-N kinetics may be a reflection of both oilseeds having high contents of unsaturated fatty acids and, consequently, similar impacts on patterns of ruminal fermentation.

Microbial non-ammonia N (NAN) flow to the small intestine, estimated by urinary PD excretion, was not affected by method of barley processing or source of supplemental fat (Table 13). Despite the existence of a relationship between duodenal supply of RNA and the urinary excretion of PD, the relationship is usually obscured by an endogenous fraction coming from the turnover of nucleic acid in tissues (Chen et al., 1990) and, therefore, results must be interpreted somewhat cautiously. In the current study, a lack of dietary effect on microbial NAN supply is consistent with the observation that, across diets, a large proportion of the GER was reabsorbed into portal blood and returned to the urea cycle (GER to ROC), and only a small proportion of the GER was utilized for anabolic purposes.

Table 7. Ingredient and chemical composition of total mixed rations with dry-rolled or pelleted barley containing canola or flax as supplemental fat sources

	Canola		Flax	
Item	Dry-rolled barley	Pelleted Barley	Dry-rolled barley	Pelleted Barley
Ingredients, % DM				
Barley silage	32.46	32.46	32.48	32.48
Alfalfa hay	17.24	17.24	17.26	17.26
Barley grain	29.81	29.81	29.39	29.39
Canola seed	8.13	8.13	-	-
Flax seed	-	-	8.30	8.30
Soybean meal	3.55	3.55	3.75	3.75
Molasses	0.40	0.40	0.40	0.40
Canola meal	3.49	3.49	3.49	3.49
Corn gluten meal	0.96	0.96	0.96	0.96
Wheat dried distillers grains	1.78	1.78	1.78	1.78
Dynamate[1]	0.18	0.18	0.18	0.18
Salt, Co-I[2]	0.33	0.33	0.33	0.33
Mineral-vitamin supplement[3]	1.66	1.66	1.66	1.66
Chemical composition				
DM, %	57.47	58.31	57.37	58.76
Starch, % of DM	22.96	22.64	24.69	23.73
CP, % of DM	17.42	17.31	17.19	17.00
NDF, % of DM	34.75	35.21	34.77	34.73
ADF, % of DM	21.04	21.37	21.00	20.85
Crude fat, % of DM	5.32	5.33	5.24	5.29

[1]Contained 18% K, 11% Mg, and 22% S.

[2]Salt, cobalt and iodine mix.

[3]Contained (per kg of premix; DM basis): 330,000 IU of vitamin A, 60,000 IU of vitamin D, 1000 IU of vitamin E, 16% Ca, 8.5% P, 6.3% Na, 4.5% Mg, 2,100 mg Zn, 1,500 mg Mn, 535 mg Cu, 12 mg Se, 45 mg I.

Table 8. Ruminal fermentation characteristics in dairy cows fed total mixed rations with dry-rolled or pelleted barley and containing canola or flaxseed as supplemental fat sources

	Canola		Flax			*P* value[1]		
Item	Dry-rolled barley	Pelleted barley	Dry-rolled barley	Pelleted barley	SEM	BP	OS	BP x OS
Ruminal pH	6.13	5.73	5.99	5.77	0.11	0.05	0.66	0.48
Ammonia, mg/dL	19.9	13.9	17.2	15.5	1.3	0.02	0.65	0.27
Volatile fatty acids, m*M*								
Acetate	90.0	74.0	85.8	73.6	1.4	<0.001	0.13	0.20
Propionate	31.1	35.7	28.3	37.3	2.1	0.007	0.50	0.31
Isobutyrate	0.38	0.28	0.34	0.26	0.02	<0.001	0.08	0.37
Butyrate	19.0[a]	15.4[b]	17.7[b]	16.1[b]	0.7	<0.001	0.41	0.002
Isovalerate	0.96	0.66	1.05	0.63	0.07	<0.001	0.91	0.76
Valerate	1.93	2.58	1.71	2.96	0.31	0.005	0.72	0.21
Total VFA	143.3	128.5	134.9	130.6	3.4	0.007	0.35	0.13
Acetate:propionate ratio	3.0[a]	2.4[b]	3.2[a]	2.2[c]	0.13	<0.001	0.05	0.006

[1]BP = method of barley processing (dry-rolled *vs* pelleted); OS = source of supplemental fat (canola *vs* flax); BP x OS = interaction.

[a-c]Means within rows with different superscripts differ ($P < 0.05$).

Table 9. Dry matter intakes (DMI) and total tract nutrient digestibilities in dairy cows fed total mixed rations with dry-rolled or pelleted barley and containing canola or flaxseed as supplemental fat sources

	Canola		Flax			*P* value[1]		
Item	Dry-rolled barley	Pelleted barley	Dry-rolled barley	Pelleted barley	SEM	BP	OS	BP x OS
DMI, kg/d	22.3	21.1	23.8	20.5	1.0	0.04	0.65	0.34
Nutrient digestibility, %								
DM	69.2	67.5	68.3	68.4	2.7	0.78	0.99	0.75
Starch	89.8	98.5	89.8	99.0	1.2	<0.0001	0.85	0.85
Crude fat	88.1	88.6	86.7	87.1	1.3	0.8	0.31	0.95
ADF	45.7	37.6	43.3	43.7	4.9	0.44	0.71	0.40
NDF	47.3	42.7	45.8	47.1	4.2	0.71	0.74	0.50
OM	70.6	69.2	69.7	70.3	2.7	0.88	0.97	0.73

[1]BP = method of barley processing (dry-rolled *vs* pelleted); OS = source of supplemental fat (canola *vs* flax); BP x OS = interaction.

Table 10. Milk yield and milk composition in dairy cows fed total mixed rations with dry-rolled or pelleted barley and containing canola or flaxseed as supplemental fat sources

	Canola		Flax			*P* value[1]		
Item	Dry-rolled barley	Pelleted barley	Dry-rolled barley	Pelleted barley	SEM	BP	OS	BP x OS
Actual milk yield, kg/d	32.3	32.4	33.1	28.1	3.42	0.41	0.56	0.39
Energy-corrected milk yield[2], kg/d	31.4	30.1	29.8	27.6	2.02	0.29	0.23	0.74
Fat, %	3.40	2.63	3.54	2.71	0.32	<0.0001	0.37	0.77
Fat yield, kg/d	1.10	0.80	1.15	0.72	0.04	<0.0001	0.78	0.09
Protein, %	2.98	3.18	3.16	3.30	0.15	0.005	0.01	0.62
Protein yield, kg/d	0.96[ab]	1.00[a]	1.03[a]	0.89[b]	0.05	0.13	0.45	0.006

[1]BP = method of barley processing (dry-rolled *vs* pelleted); OS = source of supplemental fat (canola *vs* flax); BP x OS = interaction.

[2]Energy-corrected milk yield = milk yield corrected to 3.5% fat and 3.2% protein using the following equation: ECM, kg = (12.82 x kg fat) + (7.13 x kg protein) + (0.323 x kg milk) (Tyrrell and Reid, 1965).

[a,b]Means within rows with different superscripts differ ($P < 0.05$).

Table 11. N balance, N digestibility, and plasma urea-N in dairy cows fed total mixed rations with dry-rolled or pelleted barley and containing canola or flaxseed as supplemental fat sources

	Canola		Flax			*P* value[1]		
Item	Dry-rolled barley	Pelleted barley	Dry-rolled barley	Pelleted barley	SEM	BP	OS	BP x OS
N intake, g/d	622.9	583.1	653.2	539.5	29.1	0.02	0.82	0.23
Fecal N, g/d	159.8	132.4	196.9	116.2	12.8	0.002	0.44	0.06
Urine N, g/d	291.1	261.8	266.5	242.7	54.8	0.64	0.70	0.96
Milk N, g/d	150.5	158.5	162.0	137.0	11.8	0.49	0.68	0.19
N digestibility, %	74.1	77.1	70.5	78.3	2.5	0.05	0.65	0.35
N retention, g/d	21.5	30.4	27.8	43.7	47.9	0.80	0.84	0.94
Plasma urea-N, mg/dL	17.1	14.4	15.3	15.1	1.1	0.20	0.62	0.26

[1]BP = method of barley processing (dry-rolled *vs* pelleted); OS = source of supplemental fat (canola *vs* flax); BP x OS = interaction.

Table 12. Urea-N recycling kinetics as measured using 4-d continuous jugular infusions of [$^{15}N^{15}N$]urea in dairy cows fed total mixed rations with dry-rolled or pelleted barley and containing canola or flaxseed as supplemental fat sources

	Canola		Flax			*P* value[1]		
Item	Dry-rolled barley	Pelleted barley	Dry-rolled barley	Pelleted barley	SEM	BP	OS	BP x OS
Urea-N kinetics, g/d								
Production, UER	400.9	364.1	483.4	304.5	30.2	0.02	0.74	0.08
Entry to GIT, GER	247.5	234.1	298.3	169.9	28.6	0.07	0.84	0.12
Return to ornithine cycle, ROC	183.3[ab]	180.8[ab]	224.9[a]	138.2[b]	14.2	0.03	0.98	0.04
Loss to feces, UFE	7.75	8.32	10.27	6.42	1.07	0.21	0.80	0.11
Loss to urine, UUE	153.4	130.0	185.2	134.6	12.9	0.05	0.25	0.38
Re-use for anabolism, UUA	56.5	45.0	63.1	25.2	18.3	0.27	0.75	0.53
Fractional urea-N transfers								
UER to urine	0.390	0.352	0.389	0.420	0.052	0.94	0.48	0.46
UER to GIT	0.610	0.648	0.611	0.580	0.040	0.94	0.48	0.46
GER to ROC	0.761	0.777	0.768	0.804	0.055	0.68	0.78	0.87
GER to feces	0.033	0.035	0.037	0.035	0.005	0.88	0.73	0.69
GER to UUA	0.206	0.188	0.195	0.161	0.056	0.68	0.76	0.89

[1]BP = method of barley processing (dry-rolled *vs* pelleted); OS = source of supplemental fat (canola *vs* flax); BP x OS = interaction.

[a,b]Means within rows with different superscripts differ ($P < 0.05$).

Table 13. Urinary output, urinary purine derivative (PD) excretion and microbial N supply in dairy cows fed total mixed rations with dry-rolled or pelleted barley and containing canola or flaxseed as supplemental fat sources

	Canola		Flax			*P* value[1]		
Item	Dry-rolled barley	Pelleted barley	Dry-rolled barley	Pelleted barley	SEM	BP	OS	BP x OS
Urinary excretion								
Total output, kg/d	22.3	29.5	31.4	29.7	4.4	0.53	0.31	0.33
Allantoin, mmol/d	295.6	308.8	358.2	276.9	37.3	0.38	0.69	0.22
Uric acid, mmol/d	53.7	56.7	66.6	54.3	5.6	0.43	0.37	0.20
Total PD, mmol/d	349.2	365.5	424.7	331.2	40.9	0.36	0.62	0.20
Microbial N[2], g/d	248.4	262.2	312.9	233.0	34.9	0.46	0.62	0.20

[1]BP = method of barley processing (dry-rolled *vs* pelleted); OS = source of supplemental fat (canola *vs* flax); BP x OS = interaction.

[2]Microbial N supply was calcuiated according to Chen and Gomes (1992), with an estimated endogenous PD of 56.86 mmol/d according to Gonzalez-Ronquillo et al. (2003).

3. EXPERIMENT 3:

3.1. Diets and Ingredients: The experimental diets were designed to study the effects of two levels of dietary CP (10% vs. 13%) and two levels of dietary RDP (64.5% vs. 71.0%) (Table 14). The dietary ingredients included barley grain, oat hulls, canola meal and heated canola meal and were selected because of both their CP and RDP levels. Heating of canola meal results in a shift in the site of protein digestion from the rumen to the intestine (McKinnon et al., 1995). By choosing canola meal and altering its protein digestibility through heating we can minimize rumen changes due to different dietary ingredients between the different diets. Therefore, the same dietary ingredients were used in the experimental diets but level and processing of individual ingredients were manipulated. Chemical analysis of diets showed CP levels slightly elevated (10.8% and 13.9%) from actual intended CP levels (10% and 13%), but the differences between the dietary levels of CP remained close to what was anticipated. Experimental diet RDP levels were determined using in situ incubation of dietary ingredients. The effective CP degradability of canola meal was higher than that of the heated canola meal, as would be expected. However, the effective CP degradability of heated canola meal was higher (58.8% RDP) than would be expected based on previous findings. This may in part, be due to the fact that heated canola meal was obtained in a previously ground and then pelleted form, which was subsequently ground prior to in situ incubations. This method of processing may have impacted the degradability of the canola meal when measured using the in situ technique.

3.2. Rumen Fermentation Characteristics: The average rumen pH was not significantly altered by dietary treatment ($P > 0.05$; Table 15) and was around pH 6. As expected, there was diurnal variation in rumen pH relative to feeding (data not shown). Typically, after feeding there was a gradual drop in rumen pH, which was at its lowest approximately 4 hours post meal time, and was in response to the rumen fermentation of ingested feed, as reported by others (Owens et al.,

1998). Also, rumen VFA concentrations changes relative to feeding (data not shown). Rumen concentrations of acetate, propionate, butyrate, isobutyrate, valerate and isovalerate were unaffected by dietary CP level or dietary RDP level ($P > 0.05$), except for butyrate concentration which increased as dietary RDP level decreased ($P = 0.02$; Table 15). Rumen concentration of total VFA and acetate:propionate ratio were unaffected by dietary treatment ($P > 0.05$; Table 15).

Rumen NH_3-N concentration ranged from 1.9 to 4.7 mg/dL and mean rumen NH_3-N concentration at all times post feeding were <5 mg/dL, except at 0400 h for the high CP diets (data not shown). Mean rumen NH_3-N concentration was greater ($P = 0.004$; Table 15) in heifers fed the high CP diets as compared to the low CP diets but was unaffected by dietary RDP level ($P > 0.05$; Table 15). Satter and Slyter (1974) suggest that the optimum rumen NH_3-N concentration to maximize microbial protein synthesis is >5 mg/dL but that 2 mg/dL is the actual limiting concentration of NH_3-N. Therefore, animals in the current experiment spent long periods of time with rumen NH_3-N levels below those which optimize microbial protein synthesis.

Osmotic pressure affects the passage of water through membranes and is dependent on the concentration of dissolved materials, such as ammonia and soluble minerals in rumen fluid (Owens et al., 1998). The present study found osmolality to vary from 203.0 to 242.2 mOsm/L and was found to be significantly higher for those diets with lower dietary CP level ($P = 0.03$; Table 15). Garza et al (1989) stated that a normal range for rumen osmotic pressure would be 240 to 265 mOsm/L on roughage diets and 280 to 300 mOsm/L on concentrate diets. Therefore, osmolality values in the present study are not within the expected normal range, however, this may be a reflection of the low rumen ammonia-N concentrations also found in the present study.

3.3. Intake, and Nutrient Digestibility: Dry matter intake (**DMI**) was unaffected by dietary CP or RDP level ($P > 0.05$; Table 16). Whole-tract digestibility of DM, ADF and NDF were unaffected by dietary treatment ($P > 0.05$; Table 16); however, whole-tract digestibility of ether extract increased as the level of dietary CP increased ($P = 0.01$; Table 16). There was a tendency ($P = 0.07$; Table 16) for organic matter (**OM**) digestibility to increase as RDP level increased.

3.4. N Balance and Plasma Urea-N: Heifers fed the high CP diet tended ($P = 0.08$; Table 17) to have greater N digestibility than heifers fed the low CP diet. As expected, the heifers fed the high CP diets consumed more N (34 g/d) as compared with the heifers on the low CP diets ($P = 0.01$; Table 17). Urinary N excretion ($P = 0.02$; Table 17) were both greater in heifers fed the higher level of CP diets. These findings are in accordance with similar findings in both beef steers (Archibeque et al, 2001) and dairy heifers (Marini and Van Amburgh, 2003). Fecal N output was unaffected by dietary treatment (P>0.05; Table 17). Nitrogen retained tended ($P = 0.09$; Table 17) to be greater for heifers on the high CP diets as compared to the heifers on the low CP diets. but was unaffected by dietary RDP level ($P > 0.05$; Table 17) and all heifers were in a positive N balance.

Plasma urea-N (**PUN**) was greater ($P = 0.034$; Table 17) in heifers fed the higher CP diets when compared to those fed the lower CP diets; however, PUN was unaffected by dietary RDP level ($P = 0.92$; Table 17). A lower PUN level on lower CP diets would be expected due to the increased need for rumen reabsorption of urea-N.

3.5. Urea-N Recycling Kinetics: Endogenous production of urea-N (UER) was higher ($P = 0.03$) in beef heifers fed with a higher level of dietary CP, but was unaffected by dietary RDP level ($P > 0.05$; Table 18). However, the amounts of endogenous urea-N production partitioned to the GIT (GER; $P = 0.81$) and urea-N utilized for anabolic purposes (UUA; $P = 0.72$) were unaffected by dietary treatment (Table 6). Urea-N returned to the ornithine cycle (ROC; $P = 0.07$) tended to

increase as dietary CP level increased, whereas urea-N transferred to the feces (UFE; $P = 0.06$) tended to decrease as dietary CP level increased (Table 18). Urinary urea-N excretion (UUE; $P = 0.04$) increased as dietary CP level increased and tended to increase as dietary RDP level increased ($P = 0.06$; Table 18). Fractional transfers of urea-N were largely unaffected by dietary treatment; however, the proportion of GER that was voided in the feces (GER to feces; $P = 0.02$) decreased as dietary CP level increased (Table 6).

The differences shown in urea-N entry rate at different CP levels could be due to the higher rumen NH_3-N (Table 6; $P = 0.004$) levels at higher dietary CP levels and the subsequent greater ammonia detoxification by the liver. In addition, it has been shown (Reynal and Broderick, 2005) that the lower rumen NH_3-N levels impact microbial growth and fermentation. In the present study this may be reflected by the numerically lower microbial NAN supply at a lower dietary CP level (50.7 to 71.0 g of microbial N/d in low CP diet *vs* high CP diet, respectively).

The tendency ($P = 0.06$; Table 7) for urea-N transferred to the feces (UFE) to decrease as dietary CP level increased may be the result of a propensity for dietary N digestibility to increase ($P = 0.08$; Table 16) as well as a tendency for an increase in whole body N retention as dietary CP level increased ($P = 0.09$; Table 17). Other authors (Ruiz et al., 2002) have reported improvements in N digestibility as a response to increased dietary protein intake, which could be related to the increase in rumen NH_3-N at higher dietary CP (Table 15; $P = 0.004$), in the present study.

Urinary excretion of allantoin, uric acid and total purine derivatives (i.e., allantoin + uric acid) were unaffected by dietary treatment ($P > 0.05$; Table 19). Microbial non-ammonia N **(NAN)** flow to the small intestine, which was estimated using urinary purine derivative **(PD)** excretion, was unaffected neither by dietary CP level nor dietary RDP level ($P > 0.05$; Table 19).

Microbial NAN supply was unaffected by diet possibly because the experimental diets were high in N, suggesting that factors other than N supply limited microbial production.

Table 14. Ingredients and chemical composition of diets fed to beef heifers

	10% CP		13% CP	
	64.5%	71.0%	64.5%	71.0%
Item	RDP	RDP	RDP	RDP
Ingredients, % as fed				
Barley Grain	55.0	5.0	48.0	48.0
Oat Hulls	35.0	35.0	32.0	32.0
Canola Meal	5.0	0.0	5.0	8.0
Heated Canola Meal	0.0	5.0	0.0	7.8
Premix	5.0	5.0	5.0	5.0
Chemical composition				
DM, %	89.9	88.7	89.8	89.6
OM, % of DM	95.6	95.3	95.1	95.1
CP, % of DM	10.8	10.8	13.9	14.0
NDF, % of DM	38.6	38.6	37.8	37.5
ADF, % of DM	17.9	16.8	18.4	183
EE, % of DM	2.2	2.1	2.5	2.3

Table 15. Ruminal fermentation characteristics in beef heifers fed diets with different levels of CP and RDP

	10% CP		13% CP			*P* value		
	64.5%	71.0%	64.5%	71.0%				
Item	RDP	RDP	RDP	RDP	SEM	CP	RDP	CP x RDP
Ruminal pH	6.0	6.2	6.1	6.1	0.2	0.68	0.38	0.47
Ammonia-N, mg/dL	2.2	1.9	4.1	4.7	0.6	0.004	0.80	0.53
Osmolality, mmol/kg	242.2	229.0	203.0	215.9	10.6	0.03	0.99	0.21
Volatile fatty acids, m*M*								
Acetate	55.6	59.7	62.1	61.5	5.5	0.47	0.76	0.68
Propionate	48.5	35.3	36.6	38.3	5.6	0.44	0.33	0.21
Isobutyrate	0.2	0.2	0.2	0.2	0.0	0.93	0.82	0.78
Butyrate	9.3	7.6	9.7	6.9	1.4	0.86	0.02	0.51
Isovalerate	9.8	8.6	9.1	9.0	0.9	0.88	0.46	0.48
Valerate	1.0	0.9	0.9	0.9	0.09	0.87	0.46	0.49
Total VFA	123.5	112.3	118.6	116.9	4.7	0.97	0.11	0.24
Acetate:propionate ratio	1.3	2.3	2.0	1.9	0.5	0.83	0.37	0.31

Table 16. Dry matter intakes (DMI) and total tract nutrient digestibilities in beef heifers fed with different levels of CP and RDP

	10% CP		13% CP			*P* value		
	64.5%	71.0%	64.5%	71.0%				
Item	RDP	RDP	RDP	RDP	SEM	CP	RDP	CP x RDP
DMI, kg/d	8.0	7.5	7.6	7.4	0.5	0.61	0.75	0.51
Nutrient digestibility, %								
DM	71.1	74.2	75.0	72.6	1.3	0.43	0.80	0.06
OM	72.2	75.4	73.8	76.0	1.4	0.42	0.07	0.75
EE	89.9	90.2	91.3	92.0	0.5	0.01	0.36	0.72
ADF	38.5	43.6	40.9	47.5	4.8	0.52	0.25	0.88
NDF	42.9	50.1	44.6	50.8	4.6	0.80	0.17	0.92

Table 17. N balance, N digestibility, and plasma urea-N in beef heifers fed diets with different levels of CP and RDP

	10% CP		13% CP			*P* value		
	64.5%	71.0%	64.5%	71.0%				
Item	RDP	RDP	RDP	RDP	SEM	CP	RDP	CP x RDP
N intake, g/d	138.5	130.1	171.7	165.3	10.8	0.01	0.51	0.93
Fecal N, g/d	28.7	26.9	30 3	28.6	2.4	0.50	0.47	0.98
Urine N, g/d	50.7	49.0	69.5	72.9	7.7	0.02	0.92	0.75
Urine urea-N (UUN), g/d	36.5	43.1	44.6	61.3	5.1	0.04	0.06	0.35
UUN:urine-N ratio	0.7	0.9	0.7	0.9	0.1	0.92	0.17	0.88
N digestibility %	79.2	79.4	82.0	82.6	1.6	0.08	0.79	0.89
N retention, g/d	59.1	54.2	71.0	70.0	15.1	0.27	0.91	0.86
Plasma urea-N, mg/dL	10.3	8.9	12.3	13.6	0.9	.00	0.92	0.16

Table 18. Urea-N recycling kinetics as measured using 4-d continuous jugular infusions of [$^{15}N^{15}N$]urea in beef heifers fed diets with different levels of CP and RDP

	10% CP		13% CP			*P* value		
Item	64.5% RDP	71.0% RDP	64.5% RDP	71.0% RDP	SEM	CP	RDP	CP x RDP
Urea-N kinetics, g/d								
Production, UER	135.0	131.7	165.7	166.9	10.8	0.03	0.92	0.84
Entry to GIT, GER	98.4	93.3	121.1	105.6	11.3	0.81	0.40	0.67
Return to ornithine cycle, ROC	70.3	69.8	84.0	86.2	3.5	007	0.90	0.84
Loss to feces, UFE	2.7	2.6	2.0	2.1	0.2	0.06	0.95	0.68
Loss to urine, UUE	36.5	43.1	44.6	61.3	5.1	0.04	0.06	0.35
Re-use for anabolism, UUA	25.4	20.9	35.1	17.2	7.7	0.72	0.21	0.43
Fractional urea-N transfers								
UER to urine	0.268	0.311	0.277	0.371	0.04	0.38	0.11	0.50
UER to GIT	0.732	0.689	0.723	0.629	0.04	0.38	0.11	0.50
GER to ROC	0.709	0.753	0.695	0.822	0.06	0.64	0.18	0.49
GER to feces	0.028	0.029	0.019	0.020	0.00	0.02	0.74	0.93
GER to UUA	0.263	0.218	0.286	0.158	0.06	0.76	0.19	0.50

Table 19. Urinary output, urinary purine derivative (PD) excretion and microbial non-ammonia nitrogen (NAN) supply in beef heifers fed diets with different levels of CP and RDP

	10% CP		13% CP			*P* value		
Item	64.5% RDP	71.0% RDP	64.5% RDP	71.0% RDP	SEM	CP	RDP	CP x RDP
Urinary excretion								
Total output, kg/d	4.5	4.4	7.0	5.9	0.7	0.01	0.44	0.51
Allantoin, mmol/d	104.1	110.7	129.0	130.2	19.9	0.29	0.85	0.90
Uric acid, mmol/d	10.0	10.2	13.0	10.4	2.5	0.54	0.64	0.59
Total PD, mmol/d	114.1	120.9	142.0	140.6	21.1	0.28	0.90	0.85
Microbial NAN supply[1]								
g microbial N/d	50.7	55.3	71.0	70.0	15.1	0.27	0.91	0.86
g microbial N/kg DOMR[2]	15.6	16.8	22.8	22.5	4.8	0.20	0.93	0.87

[1]Microbial NAN supply was calculated according to Chen and Gomes (1992), with an estimated endogenous PD of 44.44 mmol/d according to Gonzalez-Ronquillo et al. (2003)

[2]Digestible organic matter in the rumen (DOMR) = 0.65 x DOMI (ARC, 1984).

E. CONCLUSIONS AND RECOMMENDATIONS:

1. Experiment 1:

This study demonstrates that feeding barley-, corn- or oats-based TMR resulted in similar levels of intake but that feeding wheat-based TMR tended to depress DMI. Consequently fat-corrected milk yield decreased in cows fed wheat-based diets. Feeding barley-, or wheat-based TMR depressed milk fat content but milk fat yield was only depressed with the wheat-based TMR. However, milk fat yield was not adversely affected in cows on the barley-based TMR because the marginally higher milk yields achieved with this diet compensated for the milk fat depression. In spite of likely differences in ruminally-degradable starch contents of these diets, ruminal fermentation characteristics did not differ within the first 6-h after morning feeding. Nitrogen balance was similar across diets. The marginally superior production performance with barley- and corn-based TMR may have been due to a higher nutrient intake in cows on these diets compared to those on wheat-based TMR. Urine excretion of PD indicated higher microbial protein availability at the small intestine in cows fed barley-, and corn-based diets compared with those fed oats-, and wheat-based diets. The data from this study further demonstrate that, even though we perceive that the kinetics of rumen degradation of rations are a function of the nature and constituents of the feeds, using this information to manipulate rumen microbial protein synthesis does not always yield the expected response.

2. Experiment 2:

In summary, results from this study indicate that method of barley grain processing altered hepatic urea-N output and urea-N recycling to the GIT. Feeding dry-rolled barley compared to feeding pelleted barley tended to increase urea-N transfer to the GIT; however, most of this N was returned to the ornithine cycle, suggesting that a plateau in N utilization may already have been reached, thus limiting the utilization of the extra N supplied from recycled

urea-N. In consequence, even if barley grain processing altered urea-N entry into the GIT, this did not result in increased microbial protein supply at the duodenum.

3. Experiment 3:

The results of the present study indicate that increasing the level of dietary CP leads to an increase in both dietary N intake and N retention. In addition, it has been shown that significant amounts of N transit the urea-N pool daily; however, urea-N transfer to the GIT was similar across diets, and most of the urea-N which entered the GIT was returned to the ornithine cycle. This indicates that the most efficient use of feed N is not only achieved by maximizing urea-N recycling but, more importantly, by optimizing the capture of the recycled urea-N for microbial production. This may be attained by more closely matching fermentable carbohydrate and RDP levels within the rumen.

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G. LITERATURE CITED:

Al-Dehneh, A., J. T. Huber, R. Wanderley, C. B. Theurer, M. Pessarakli, and D. DeYoung. 1997. Incorporation of recycled urea-N into ruminal bacteria flowing to the small intestine of dairy cows fed a high-grain or high-forage diet. Anim. Feed Sci. Technol. 68:327–338.

Alio, A., C. B. Theurer, O. Lozano, J. T. Huber, R. S. Swingle, A. Delgado-Elorduy, P. Cuneo, D. DeYoung, and K. E. Webb, Jr. 2000. Splanchnic nitrogen metabolism by growing beef steers fed diets containing sorghum grain flaked at different densities. J. Anim. Sci. 78:1355-1363.

AOAC. 1990. Official Methods of Analysis. Vol. 1. 15th ed. Association of Official Analytical Chemists, Arlington, VA.

AOCS. 1989. Official Methods and Recommended Practices. 4th ed. American Oil Chemists' Society, Champaign, IL.

ARC, 1984. The Nutrient Requirement of Ruminant Livestock, Supplement 1. Commonwealth Agricultural Bureaux, Slough, UK.

Archibeque, S. L., J. C. Burns, and G. B. Huntington. 2001. Urea flux in beef steers: Effects of forage species and nitrogen fertilization. J. Anim. Sci. 79: 1937-1943.

Arieli, A., S. Abramson, S. J. Mabjeesh, S. Zamwel, and I. Bruckental. 2001. Effect of site and source of energy supplementation on milk yield in dairy cows. J. Dairy Sci. 84:462–470.

Bauman, D. E., and J. M. Griinari. 2001. Regulation and nutritional manipulation of milk fat:low-fat syndrome. Livest. Prod. Sci. 70:15-29.

Broderick, G. A. and J. H. Kang. 1980. Automated and simultaneous determination of ammonia and total amino acids in ruminal fluids and in vitro media. J. Dairy Sci. 63: 64-75.

Bunting, L. D., J. A. Boling, C. T. MacKown, and R. B. Muntifering. 1987. Effect of dietary protein level on N metabolism in lambs: Studies using ^{15}N. J. Anim Sci. 64:855-867.

Cabrita, A. R. J., R. J. Dewhurst, J. M. F. Abreu., and A. J. M. Fonseca. 2006. Evaluation of the effects of synchronising the availability of N and energy on rumen function and production responses of dairy cows – a review. Anim. Res. 55:1-24.

Canadian Council on Animal Care. 1993. Guide to the care and use of experimental animals. 2nd ed. Vol. 1. CCAC, Ottawa, ON.

Casper, D. P., H. A. Maiga, M. J. Brouk, and D. J. Schingoethe. 1999. Synchronization of carbohydrate and protein sources on fermentation and passage rate in dairy cows. J. Dairy Sci. 82:1779–1790.

CAST. 2002. Animal diet modification to decrease the potential for nitrogen and phosphorus pollution. Council for Agricultural Science and Technology. Issue Paper 21:1-16. Ames, Iowa.

Chase, I. F. 1994. Environmental considerations in developing dairy rations. pp. 56-62 *in* Proc. Cornell Nutr. Conf. Feed Manuf., Rochester, NY. Cornell Univ., Ithaca, NY.

Chen, X. B., and M. J. Gomes. 1992. Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives- and overview of the technical details. International Feed Resources Unit, Rowett Research Institute, Occasional Publication 1992. Available at: http://www.macaulay.ac.uk/IFRU/pdf/chema.pdf. Accessed May 2, 2007.

Chen, X. B., and M. J. Gomes. 1992. Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives in sheep. J. Sci. Food Agric. 63: 189-194.

Chen, X. B., E. R. Orskov, and F. D. DeB. Hovell. 1990. Excretion of purine derivatives by ruminants: Endogenous excretion, differences between cattle and sheep. Br. J. Nutr. 63:121–129.

Clark, J. H., T. H. Klusmeyer, and M. R. Cameron. 1992. Microbial protein synthesis and flows of nitrogen fractions to the duodenum of dairy cows. J. Dairy Sci. 75:2304–2323.

Crutchfield, W. O. 1968. A technique for placement of an in-dwelling catheter in the cow. Vet. Med. Small Anim. Clin. 63:1141-1144.

DePeters, E. J., and S. J. Taylor. 1985. Effects of feeding corn or barley on composition of milk and diet digestibility. J. Dairy Sci. 68:2027–2032.

Egan, A. R., K. Boda, and J. Varady. 1986. Regulation of nitrogen metabolism and recycling. Pages 386-402 in Control of Digestion and Metabolism in Ruminants. L. P. Milligan, W. L. Grovum and A. Dobson, eds. Prentice-Hall, Englewood Cliffs, NJ.

Engelhardt, W. V., S. Hinderer, and E. Wipper. 1978. Factors influencing the endogenous urea-N secretion and utilization in the gastrointestinal tract. Pages 4.1 – 4.12 in Ruminant Digestion and Feed Evaluation. D.F. Osbourn, D. E. Beever, and D. J. Thomson, ed. Agricultural Research Council, London, U.K.

Erwin, E. S., G. J. Marco, and E. M. Emery. 1961. Volatile fatty acids analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768–1776.

Firkins, J. L., M. L. Eastridge, N. R., St-Pierre, and S. M. Noftger. 2001. Effects of grain variability and processing on starch utilization by lactating dairy cattle. J. Anim. Sci. 79 (E. Suppl.):E218-E238.

Fossati, P., L. Prencipe and G. Berti. 1980. Use of 3,5-dichloro-2-hydroxybenzenesulfonic acid/4-aminophenazone chromogenic system in direct enzymic assay of uric acid in serum and urine. Clin. Chem. 26:227-231.

Galyean, M.L. 1996. Protein levels in beef cattle finishing diets: industry application, university research, and systems results. J. Anim. Sci. 74:2860-2870.

Garza, J. D., Owens, F. N. And Breazile, J. E. 1989. Effects of diet on ruminal liquid and on blood sserum osmolality and hematocrit in feedlot heifers. Okla. Agric. Exp. Stn. MP-127:68-76.

Gonzalez-Ronquillo, M., J. Balcells, J. A. Guada, and F. Vicente. 2003. Purine derivative excretion in dairy cows: Endogenous excretion and the effect of exogenous nucleic acid supply. J. Dairy Sci. 86:1282-1291.

Griinari, J. M., D. A. Dwyer, M. A. McGuire, D. E. Bauman, D. L. Palmquist, and K. V. Nurmela. 1998. Trans-octadecenoic acids and milk fat depression in lactating dairy cows. J. Dairy Sci. 81:1251–1261.

Grings, E. E., R. E. Roffler, and D. P. Deitelhoff. 1992. Evaluation of corn and barley as energy sources for cows in early lactation fed alfalfa-based diets. J. Dairy Sci. 75:193-200.

Haig, P. A., T. Mutsvangwa, R. Spratt, and B. W. McBride. 2002. Effects of dietary protein solubility on nitrogen losses from lactating dairy cows and comparison with predictions from the CNCPS. J. Dairy Sci. 85:1208-1217.

Hall, M. B. 2004. Short communication: Effect of carbohydrate fermentation rate on estimates of mass fermented and milk response. J. Dairy Sci. 87:1455-1456.

Heinrichs, J. 1996. Pages 1-9 in Evaluating Particle Size of Forages and TMRs using the Penn State Particle Size Separator. Pennsylvania State University, State College.

Herrera-Saldana, R., J. T. Huber, and M. H. Poore. 1990. Dry matter, crude protein and starch degradability of five cereal grains. J. Dairy Sci. 73:2386–2393.

Hettiarachchi, M., R. M. Dixon, and J. V. Nolan. Effect of intra-ruminal urea infusion and changing digestible organic matter intake on nitrogen kinetics in sheep fed rice straw. J. Agric. Sci (Cambridge) 133:109-121.

Hironaka, R., K. A. Beauchemin, and T. J. Lysyk. 1992. The effect of thickness of steam-rolled barley on its utilization by beef cattle. Can. J. Anim. Sci. 72:279–286.

Hoover, W. H., and S. R. Stokes. 1991. Balancing carbohydrate and protein for optimum rumen microbial yield. J. Dairy Sci. 74:3630-3644.

Hristov, A. N., M. Ivan, L. M. Rode, and T. A. McAllister. 2001. Fermentation characteristics and ruminal ciliate protozoal populations in cattle fed medium- or high-concentrate barley-based diets. J. Anim. Sci. 79:515–524.

Huntington, G. B. 1986. Uptake and transport nonprotein nitrogen by the ruminant gut. Fed. Proc. 45:2272-2276.

Huntington, G. B. 1989. Hepatic urea synthesis and site and rate of urea removal from blood of beef steers fed alfalfa hay or a high concentrate diet. Can. J. Anim. Sci. 69:215-223.

Huntington, G. B. 1997. Starch utilization by ruminants: From basics to the bunk. J. Anim. Sci 75:852-867.

Huntington, G. B. 1997. Starch utilization by ruminants: From basics to the bunk. J. Anim. Sci. 75:852-867.

Huntington, G. B., and S. L. Archibeque. 1999. Practical aspects of urea and ammonia metabolism in ruminants. Proc. Am. Soc. Anim. Sci. Available at: http://www.asas.org/jas/symposia/proceedings/filename. Accessed May 2, 2007.

Huntington, G. B., E. J. Zetina, J. M. Whitt, and W. Potts. 1996. Effects of dietary concentrate level on nutrient absorption, liver metabolism, and urea kinetics of beef steers fed isonitrogenous and isoenergetic diets. J. Anim. Sci. 74:908-916.

Jeffery, H., R. J. Buesnel, and G. H. O'Neill. 1976. Short-tern studies on the response of grazing dairy cows to dietary supplementation. Austr. J. Exp. Agric. Anim. Husb. 16:445-451.

Jenkins, T. C. 1993. Lipid metabolism in the rumen. J. Dairy Sci. 76: 3851-3863.

Jouany, J. P. 1996. Effect of rumen protozoa on nitrogen utilization by ruminants. J. Nutr. 126:1335S-1346S.

Kennedy, P. M., and L. P. Milligan. 1980. The degradation and utilization of endogenous urea in the gastrointestinal tract of ruminants: a review. Can. J. Anim. Sci. 60:205-221.

Khorasani, G. R., E. K. Okine, and J. J. Kennelly. 2001. Effects of substituting barley grain with corn on ruminal fermentation characteristics, milk yield, and milk composition of Holstein cows. J. Dairy Sci. 84:2760-2769.

Khorasani, G. R., G. de Boer, B. Robinson, and J. J. Kennelly. 1994. Influence of dietary protein and starch on production and metabolic responses of dairy cows. J. Dairy Sci. 77: 813-824.

Klopfenstein, T.J., and G.E. Erickson. 2002. Effects of manipulating protein and phosphorus nutrition of feedlot cattle on nutrient management and the environment. J. Anim. Sci. 80(E. Suppl. 2):E106-E114.

Koenig, K. M., K. A. Beauchemin, and L. M. Rode. 2003. Effect of grain processing and silage on microbial protein synthesis and nutrient digestibility in beef cattle fed barley-based diets. J. Anim. Sci. 81:1057-1067.

Lapierre, H., and G. E. Lobley. 2001. Nitrogen recycling in the ruminant: A review. J. Dairy Sci. 84 (Suppl.):E223–E236.

Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS System for Mixed Models. SAS Inst., Inc., Cary, NC.

Lobley, G. E., D. M. Bremner, and G. Zuur. 2000. Effects of diet quality on urea fates in sheep as assessed by refined, non-invasive [^{15}N ^{15}N] urea kinetics. Br. J. Nutr. 84:459-468.

Marini, J. C. and Van Amburgh, M. E. 2003. Nitrogen metabolism and recycling in Holstein heifers. J Anim Sci 81: 545-552.

Marini, J. C., J. M. Klein, J. M. Sands, and M. E.Van Amburgh. 2004. Effect of intake on nitrogen recycling and urea transporter abundance in lambs. J. Anim. Sci. 82:1157-1164.

Marsh, W. H., B. Fingerhunt, and E. Kirsch. 1957. Determination of urea N with the diacetyl method and an automatic dialyzing apparatus. Am. J. Clin. Pathol. 28:681-688.

McAllister, T. A., R. C. Phillippe, L. M. Rode, and K.-J. Cheng. 1993. Effect of the protein matrix on the digestion of cereal grains by ruminal microorganisms. J. Anim. Sci. 71:205-212.

McCarthy, Jr., R. D., T. H. Klusmeyer, J. L. Vicini, J. H. Clark, and D. R. Nelson. 1989. Effects of source of protein and carbohydrate on ruminal fermentation and passage of nutrients to the small intestine of lactating cows. J. Dairy Sci. 72:2002–2016.

McCleary, B. V., V. Solah, and T. S. Gibson. 1994. Quantitative measurement of total starch in cereal flours and products. J. Cereal Sci. 20:51–58.

McKinnon, J. J., Olubobkun, J. A., Mustafa, A., Cohen, R. D. H. and Christensen, D. A. 1995. Influence of dry heat treatment of canola meal on site and extent of nutrient disappearance in ruminants. Anim. Feed Sci. Technol. 56: 243-252.

Moran, J. B. 1986. Cereal grains in complete diets for dairy cows: A comparison of rolled barley, wheat and oats and of three methods of processing oats. Anim. Prod. 43:27-36.

National Research Council. 1996. Nutrient Requirements of Beef Cattle. 7th. rev. ed. Nat'l Acad. Sci. Washington, DC.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, D.C.

Nocek, J. E. and Russell, J. B. 1988. Protein and energy as an integrated system. Relationship of ruminal protein and carbohydrate availability to microbial synthesis and milk production. J. Dairy Sci. 71: 2070-2107.

Nocek, J. E., and S. Tamminga. 1991. Site of digestion of starch in the gastrointestinal tract of dairy cows and its effects on milk yield and composition. J. Dairy Sci. 74:3598-3629.

Oh, Y.G., K. H. Kim, J. H. Kim, J. J. Choung and D. G. Chamberlain. 1999. The effect of the form of nitrogen in the diet on ruminal fermentation and the yield of microbial protein in sheep consuming diets of grass silage supplemented with starch or sucrose. Anim. Feed Sci. Technol. 78:227-237.

Oldick, B. S., and J. L. Firkins. 2000. Effects of degree of fat saturation on fiber digestion and microbial protein synthesis when diets are fed twelve times daily. J. Anim. Sci. 78:2412-2420.

Onetti, S. G., R. D. Shaver, M. A. McGuire, D. L. Palmquist, and R. R. Grummer. 2002. Effect of supplemental tallow on performance of dairy cows fed diets with different corn silage:alfalfa silage ratios. J. Dairy Sci. 85:632–641.

Orskov, E. R., C. Fraser, V. C. Mason, and S. O. Mann. 1970. Influence of starch digestion in the large intestine of sheep on caecal fermentation, caecal microflora and faecal nitrogen excretion. Br. J. Nutr. 24:671.

Owens, F. N., Secrist, D. S., Hill, W. J. and Gill, D. R. 1998. Acidosis in cattle: a review. J Anim Sci 76(1): 275-286.

Pantoja, J., J. L. Firkins, M. L. Eastridge, and B. L. Hull. 1994. Effects of fat saturation and source of fiber on site of nutrient digestion and milk production by lactating dairy cows. J. Dairy Sci. 77:23412356.

Penner, G.B., K. A. Beauchemin, and T. Mutsvangwa. 2006. An Evaluation of the Accuracy and Precision of a Stand-Alone Submersible Continuous Ruminal pH Measurement System. J. Dairy Sci. 89:2132-2140.

Qui, X., M. L. Eastridge, and J. L. Firkins. 2004. Effects of dry matter intake, addition of buffer, and source of fat on duodenal flow and concentration of conjugated linoleic acid and *trans*-11 $C_{18:1}$ in milk. J. Dairy Sci. 87:4278-4286.

Raes, K., S. De Smet, and D. Demeyer. 2004. Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb, beef and pork meat; a review. Anim. Feed Sci. Technol. 113:199–221.

Rémond, D., F. Meschy, and R. Boivin. 1996. Metabolites, water and mineral exchanges cross the rumen wall: Mechanisms and regulation. Ann. Zootech. 45:97-119.

Rémond, D., J. P. Chaise, E. Delval, and C. Poncet. 1993. Net flux of metabolites across the ruminal wall of sheep fed twice a day with orchardgrass hay. J. Anim. Sci. 71:2529-2538.

Reynal, S. M. and Broderick, G. A. 2005. Effect of dietary level of rumen-degraded protein on production and nitrogen metabolism in lactating dairy cows. J. Dairy Sci. 88: 4045-4064.

Reynal, S. M., G. A. Broderick, and C. Bearzi. 2005. Comparison of four markers for quantifying microbial protein flow from the rumen of lactating dairy cows. J. Dairy Sci. 88: 4065-4082.

Reynolds, C. K., and G. B. Huntington. 1988. Partition of portal-drained visceral next flux in beef steers. 1. Blood flow and net flux of oxygen, glucose and nitrogenous compounds across stomach and post-stomach tissues. Br. J. Nutr. 60:539-551.

Ruiz, R., Tedeschi, L. O., Marini, J. C., Fox, D. G., Pell, A. N., Jarvis, G. and Russell, J. B. 2002. The effect of ruminal nitrogen (N) deficiency in dairy cows: Evaluation of the Cornell Net Carbohydrate and Protein System Ruminal N Deficiency Adjustment 1. J. Dairy Sci. 85: 2986-2999.

Russell, J. B., and D. B. Wilson. 1996. Why are ruminal cellulolytic bacteria unable to digest cellulose at low pH? J. Dairy Sci. 79:1503-1509.

Sarraseca, A., E. Milne, M. J. Metcalf, and G. E. Lobley. 1998. Urea recycling in sheep: Effects of intake. Br. J. Nutr. 79:79-88.

SAS Institute. 2004. SAS/STAT 9.1 User's Guide. SAS Institute Inc., Cary, NC.

Satter, L. G., and L. L. Slyter.1974. Effect of ammonia concentration on rumen microbial protein production in vitro. Br. J. Nutr. 32:199-208.

Schauff, D. J., J. P. Elliott, J. H. Clark, and J. K. Drackley. 1992. Effects of feeding lactating dairy cows diets containing whole soybeans and tallow. J. Dairy Sci. 75:1923-1935.

Spanghero, M., and Z. M. Kowalski. 1997. Critical analysis of N balance experiments with lactating cows. Livest. Prod. Sci. 52:113-122.

Statistical Analysis System Institute Inc. (SAS). 2004. SAS/STAT 9.1 User's Guide. SAS Institute Inc., Cary, NC.

Stern, M.D., G.A. Varga, J.H. Clark, J.L. Firkins, J.T. Huber, and D.L. Palmquist. 1994. Evaluation of chemical and physical properties of feeds that affect protein metabolism in the rumen. J. Dairy Sci. 77:2762-2786.

Tamminga, S. 1992. Nutrition management of dairy cows as a contribution to pollution control. J Dairy Sci 75: 345-357.

Theurer, C. B., G. B. Huntington, J. T. Huber, R. S. Swingle, and J. A. Moore. 2002. Net absorption and utilization of nitrogenous compounds across ruminal, intestinal, and hepatic tissues of growing beef steers fed dry-rolled or steam-flaked sorghum grain. J. Anim. Sci. 80:525-532.

Theurer, C. B., J. T. Huber, A. Delgado-Elorduy, and R. Wanderley. 1999. Summary of steam-flaking corn or sorghum grain for lactating dairy cows. J. Dairy Sci. 82:1950-1959.

Theurer, C. B., O. Lozano, A. Alio, A. Delgado-Elorduy, M. Sadik, J. T. Huber, and R. Zinn. 1999. Steam-processed corn and sorghum grain flaked at different densities alter ruminal,

small intestinal, and total tract digestibility of starch by steers. J. Anim. Sci. 77:2824-2831.

Tommervik, R. S., and D. E. Waldern. 1969. Comparative feeding value of wheat, corn, barley, milo, oats and a mixed concentrate ration for lactating cows. J. Dairy Sci. 52:68-73.

Tyrrell, H. F., and J. T. Reid. 1965. Prediction of the energy value of cow's milk. J. Dairy Sci. 48:1215–1223.

Van Horn, H. H., G. L. Newton and W. E. Kunkle. 1996. Ruminant nutrition from an environmental perspective: factors affecting whole-farm nutrient balance. J. Anim. Sci. 74:3082-3102.

Van Nevel, C. J. and D. I. Demeyer. 1996. Influence of pH on lipolysis and biohydrogenation of soybean oil by rumen contents in vitro. Rep. Nutr. Dev. 36:53-63.

Van Soest, P. J. 1994. Function of the ruminant forestomach. Pages 230–252 in Nutritional Ecology of the Ruminant. 2nd ed. Cornell University Press, Ithaca, NY.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber and non-starch polysaccharides (NSP) in relation to animal nutrition. J. Dairy Sci. 74: 3583-3597.

Vicente, F., Sarraseca, A., de Vega, A. and Guada, J. A. 2004. Performance of several Cr and Yb analytical techniques applied to samples of different biological origin (digesta or faeces). J. Sci. Food Agric. 84: 2035-2040.

Wang, Z., and L. A. Goonewardene. 2004. The use of MIXED models in the analysis of animal experiments with repeated measures data. Can. J. Anim. Sci. 84:1–11.

Ward, A. T., K. M. Wittenberg, and R. Przybylski. 2002. Bovine milk fatty acid profiles produced by feeding diets containing solin, flax and canola. J. Dairy Sci. 85:1191-1196.

Weatherburn, M. W. 1967. Phenol-hypochlorite reaction for determination of ammonia. Anal. Chem. 39:971–974.

Weiss, W. P., G. R. Fisher, and G. M. Erickson. 1989. Effect of source of neutral detergent fiber and starch on nutrient utilization by dairy cows. J. Dairy Sci. 72:2308–2315.

Williams, L. M. 2007. The effect of feeding a barley / canola meal pellet to feedlot steers on performance, rumen fermentation, and eating behaviour. M.Sc. Thesis. University of Saskatchewan.

Yang, W. Z., K. A. Beauchemin, and L. M. Rode. 2000. Effects of barley grain processing on extent of digestion and milk production of lactating cows. J. Dairy Sci. 83:554–568.

Yang, W. Z., K. A. Beauchemin, and L. M. Rode. 2001. Effects of grain processing, forage to concentrate ratio, and forage particle size on rumen pH and extent of digestion by lactating dairy cows. J. Dairy Sci. 84:2203–2216.

Yu, P., D. A. Christensen, J. J. McKinnon. 2003. Effect of variety and maturity stage on chemical composition, carbohydrate and protein subfractions, in vitro rumen degradability and energy values of timothy and alfalfa. Can J. Anim. Sci. 83. 279-290.

I. ADMINISTRATIVE AND OTHER ASPECTS:

1. PUBLICATIONS:

1.1. Peer-Reviewed Papers in Scientific Journals:

G. N. Gozho, M. R. Hobin, and T. Mutsvangwa. 2008. Interactions between barley grain processing and source of supplemental dietary fat on nitrogen metabolism and urea-nitrogen recycling in dairy cows. Journal of Dairy Science, 91: 247-259.

G. N. Gozho, and T. Mutsvangwa. 2008. Influence of carbohydrate source on ruminal fermententation characteristics, performance and microbial protein synthesis in dairy cows. Journal of Dairy Science, 91: 2726-2735.

1. 2. Abstracts Presented at Scientific Meetings:

G. N. Gozho, M. R. Hobin, and T. Mutsvangwa, 2008. Effects of barley grain processing and source of supplemental dietary fat on nutrient digestion and microbial protein synthesis in dairy cows. Journal of Dairy Science 91 (E-Suppl. 1): 69.

K. Baker, T. Mutsvangwa, J. J. McKinnon, G. Gozho, and T. A. McAllister. 2008. Effects of dietary crude protein and ruminally-degradable protein on urea recycling and microbial protein production in beef heifers. Canadian Journal of Animal Science, 88:179.

K. Baker, T. Mutsvangwa, J. J. McKinnon, G. Gozho, and T. A. McAllister. 2007. Effects of dietary crude protein and ruminally-degradable protein on urea recycling and microbial protein production in beef heifers. Proceedings of the 2nd International Symposium on Energy and Protein Metabolism. EAAP Publication No. 124: 433-434.

G. N. Gozho, M. Hobin, and T. Mutsvangwa, 2007. Interactions between oilseed supplementation and barley grain processing on urea-nitrogen recycling and nitrogen metabolism in dairy cows. Journal of Dairy Science, 90 (Suppl. 1): 101.

G. N. Gozho, and T. Mutsvangwa, 2007. Influence of carbohydrate source on nitrogen metabolism and microbial protein synthesis in dairy cows. Journal of Dairy Science. 90 (Suppl. 1): 101.

2. PERSONNEL INVOLVED:

2.1. Project Investigators:

Dr. T. Mutsvangwa (Principal Investigator)

Dr. J. J. McKinnon (Co-Investigator)

2.2. Graduate Students (GS) and Post-Doctoral Fellows (PDF):

Dr. G. N. Gozho (PDF)

Ms. K. Baker (Ph.D. student)

2.2. Support Staff

Ms. Marlene Fehr (Research Assistant)

Ms. Sujeema Abeysekara (Research Assistant for a 6-month period in 2005)

All staff of the Greenbrae Dairy Research Centre, University of Saskatchewan (involved in animal care)